The Role of Space Observations in Earth System Science: Then, Now, and Later

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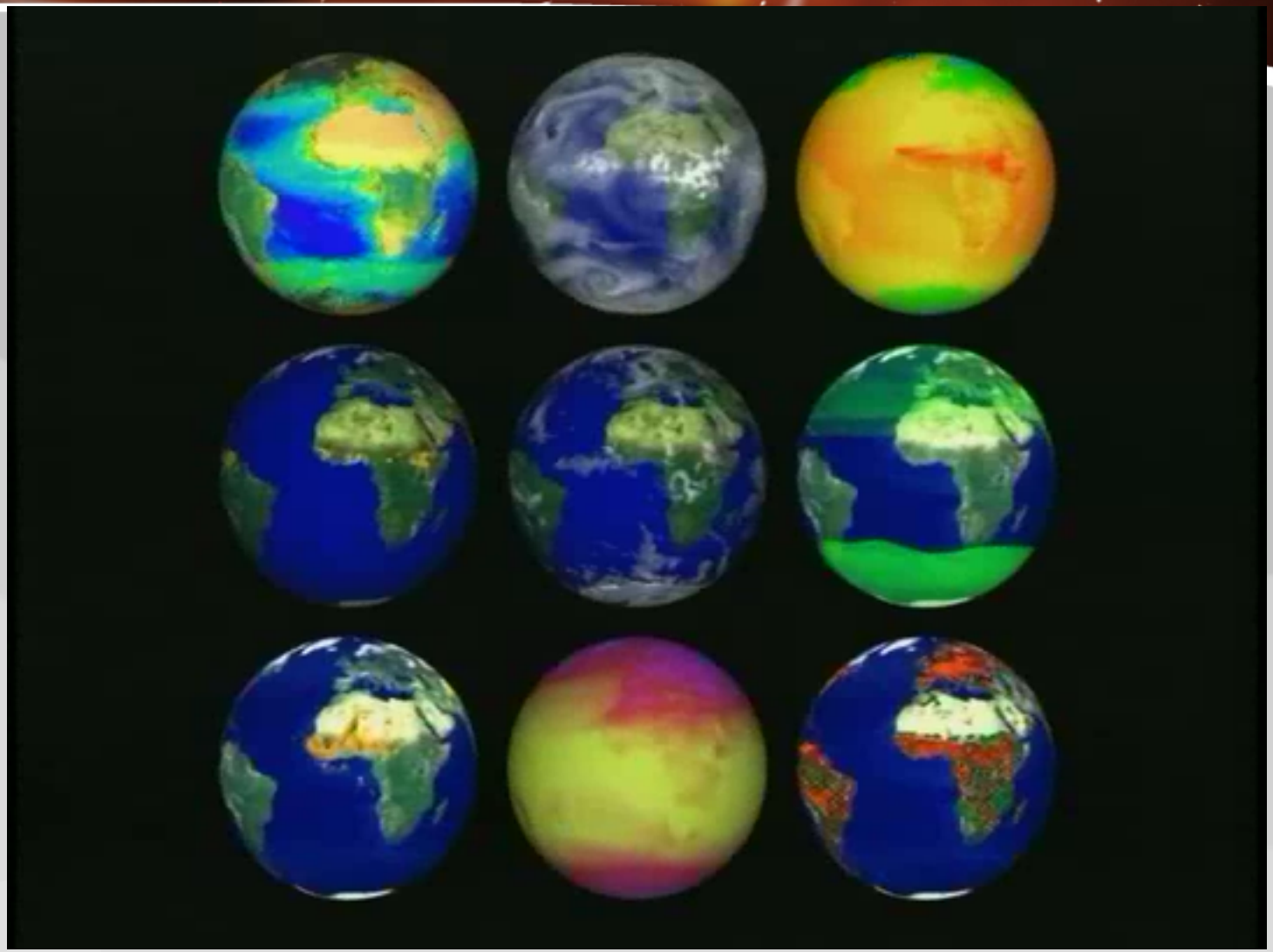
* This talk presents results provided by a large number of contributors from HQ, field canters, and our investigator community!

October 28, 2014

Overview of Talk

- Introduction – A Top Down View of the Earth
- How NASA Studies the Earth with Remote Sensing
- The Interagency and International Context
- What We're Learning
- Future Plans
- It's not ALL Satellites
- Some thoughts about the Future…
- Conclusion

The Earth is a Dynamic System...



…That Changes on all Time Scales

The Challenges of Earth System Science

SCIENTIFIC

- Documenting the status and behavior of the Earth system and its multiple, interacting components
- Documenting the evolution of the Earth system and providing understanding of the sources of that evolution
- Predicting the future evolution of the Earth system
- Making Earth system science data easily available to users for both scientific and societal purposes

ARITHMETIC

- *Satellite Data:* consider a global imager with 250 m resolution measuring once per day at 30 wavelengths for a year - ~ 10^{14} pixels/year
- *Model Output:* consider a chemistry/climate model, with 1^{o}x1^{o} resolution and 50 layers, writing out 30 parameters at hourly intervals for a year - ~ 10^{12} results written/ year

COMMUNITY

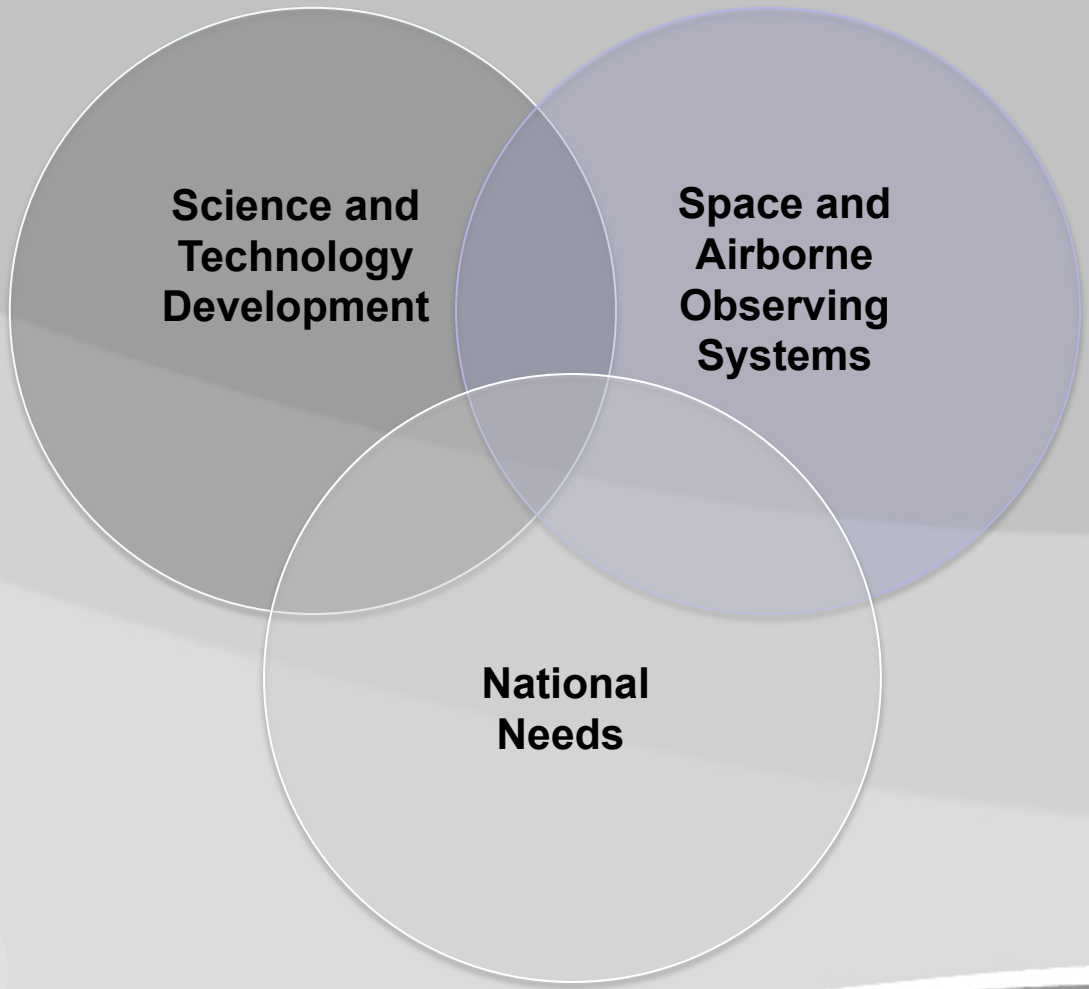
- *Research Community*: scientific researchers looking to answer fundamental questions about the Earth
- *Assessment Community*: researchers of all types looking to document information about prior and future evolution of the Earth system to inform long-term policy and decision making
- *Forecasting Community*: operational scientists and others looking to provide forecasts to the general public
- *Applications Community*: research, corporate, and non-governmental organizations looking to inform nearer term decisions for management and planning

Close-up of Home!

A flyby from Washington to Baltimore using Landsat imagery draped over elevation data

http://svs.gsfc.nasa.gov/vis/a000000/a000800/a000882/index.html

ESD's Unique National Role



NASA is the Only US Entity that Fully Occupies all Three Areas and Creates Synergy from Them!

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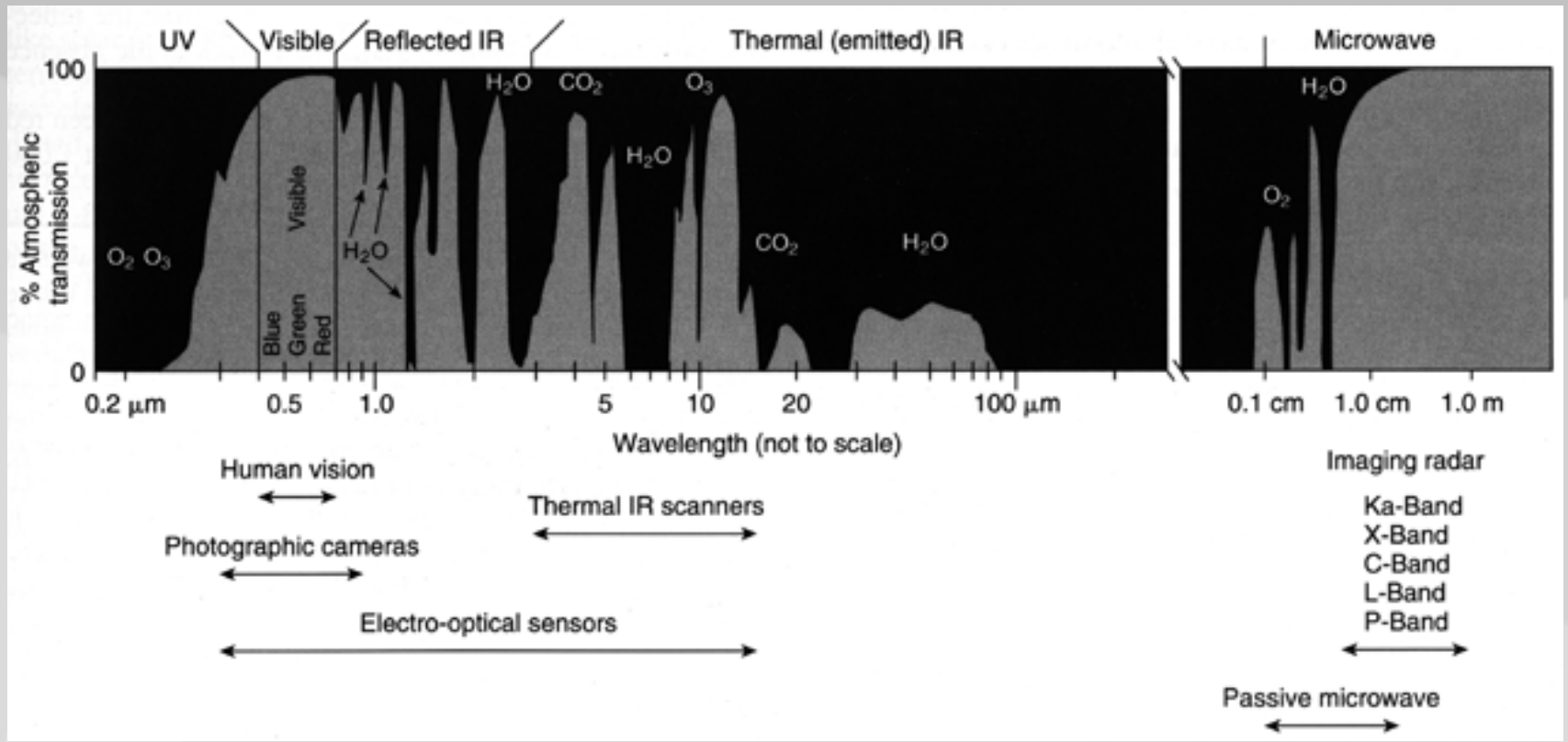
How is Remote Sensing Done?

- Space-based remote sensors allow us to observe & quantify Earth's environments in regions of the electromagnetic spectrum to which our eyes are not sensitive



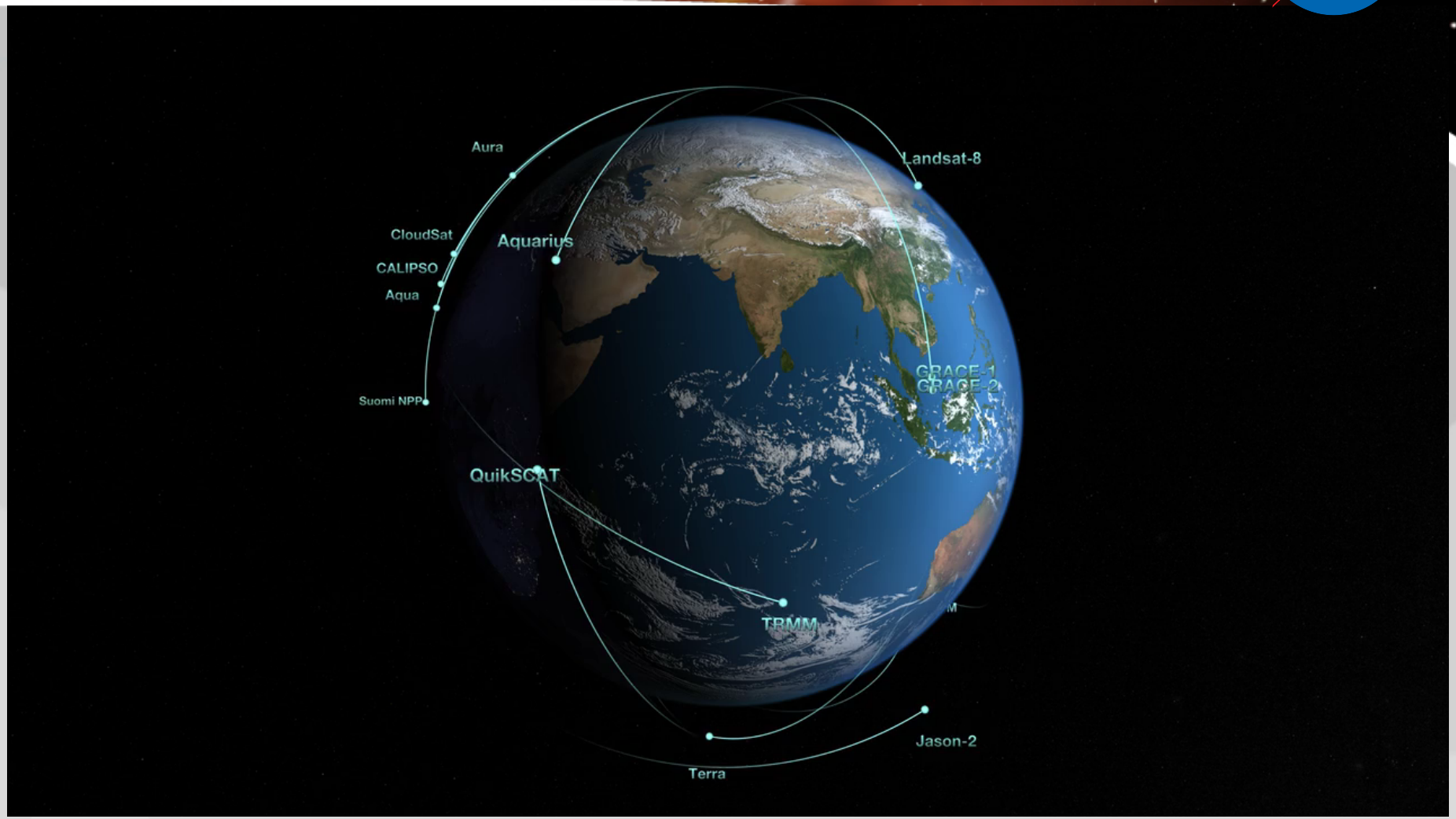
Remote Sensing "Choices"

- Once one establishes objective(s) for what one is trying to do, there are multiple choices (not all independent)
  - Wavelength region(s)
  - Viewing technique – (Emission, absorption, occultation …)
  - Viewing geometry – Limb, nadir, …
  - Orbital inclination
  - Observation time(s)
  - Swath width, repeat pattern
  - Source – Earth, Sun/Stars (for occultation), "Bring your own" (active remote sensing)

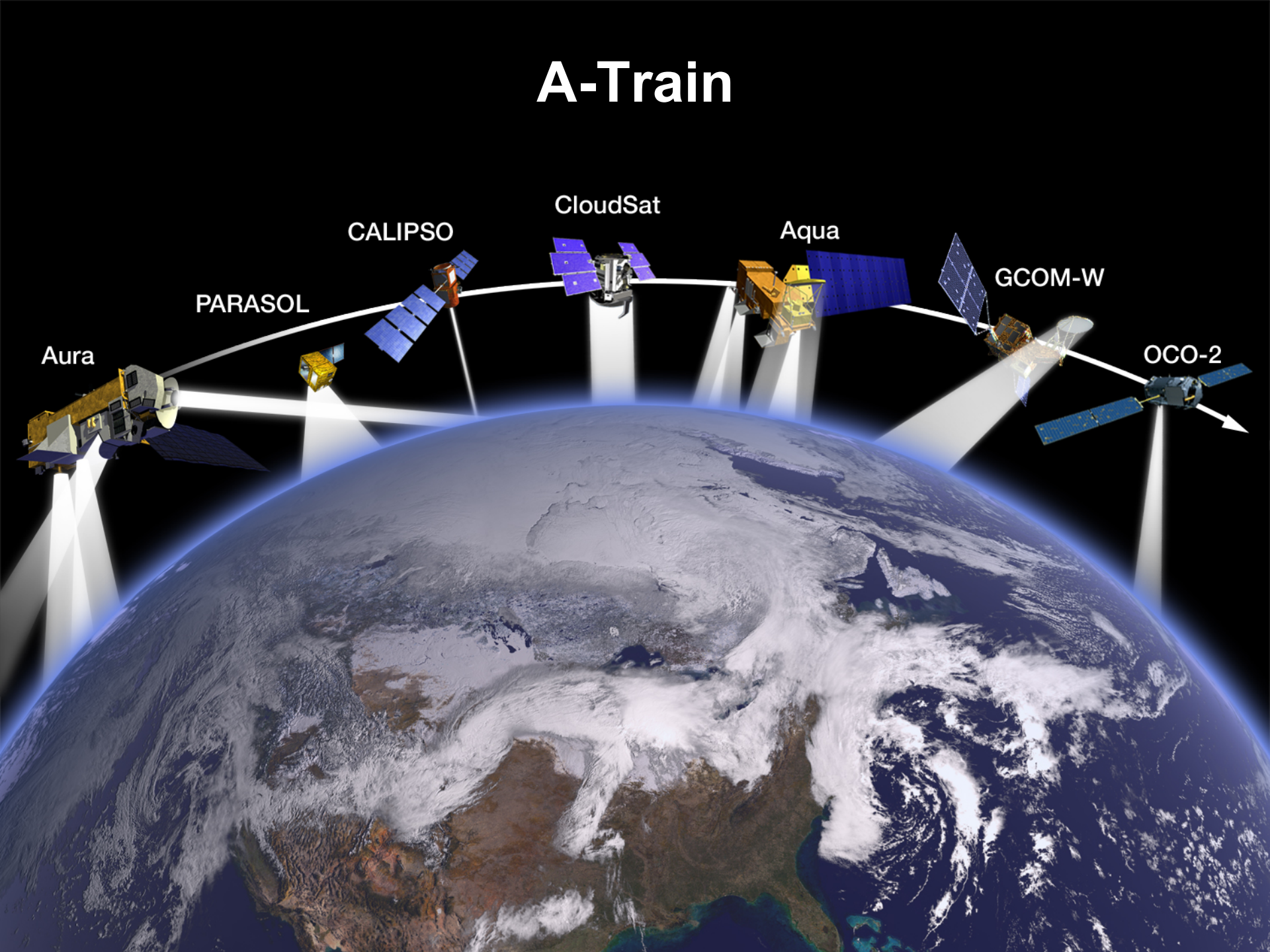
Access to Remote and Hostile Areas


NASA Earth Science
Operating Missions
2014
OSTM/Jason 2
(NOAA)
Aquarius
QuikSCAT
TRMM
Terra
RapidScat
EO-1
Suomi NPP
(NOAA)
Landsat-7
(USGS)
Aqua
LandSat 8
(USGS)
SORCE
Aura
GPM
GRACE (2)
CALIPSO
CloudSat
OCO-2

NASA Earth Science Satellite Constellation 2014



A-Train



GPM Core Observatory Launch

Launched at 1:37 p.m. EST, Feb 27, 2014

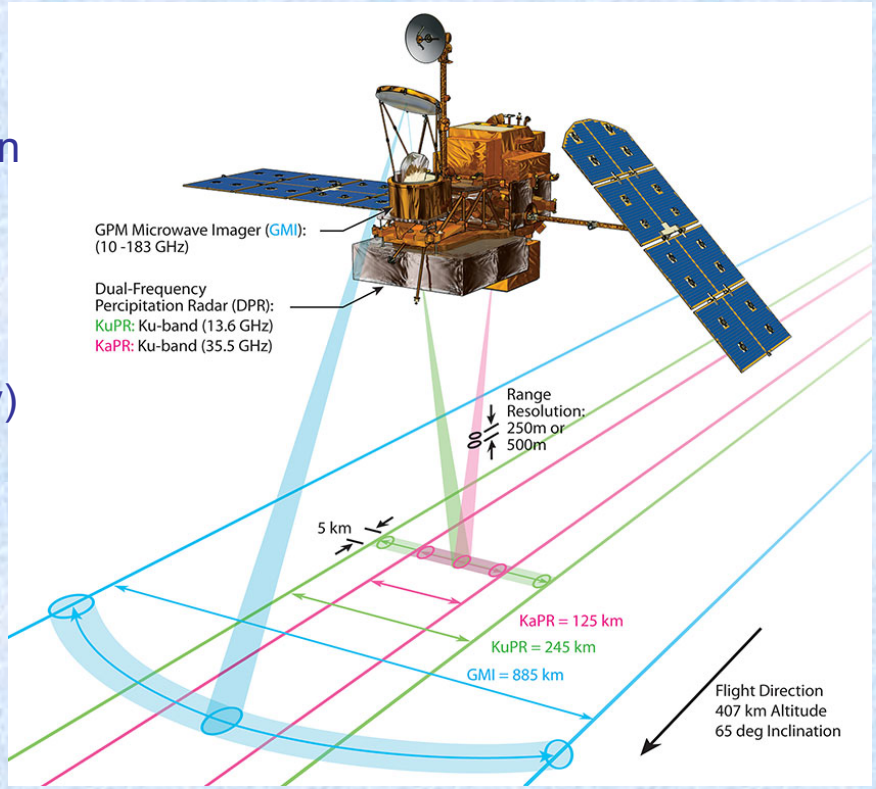
GPM Core Observatory Measurement Capabilities

Dual-Frequency (Ku-Ka band) Precipitation Radar (DPR):

- Increased sensitivity (~12 dBZ) for light rain and snow detection relative to TRMM
  - Better measurement accuracy with differential attenuation correction
- Detailed microphysical information (DSD mean mass diameter & particle no. density) & identification of liquid, ice, and mixed-phase regions

Multi-Channel (10-183 GHz) GPM Microwave Imager (GMI):

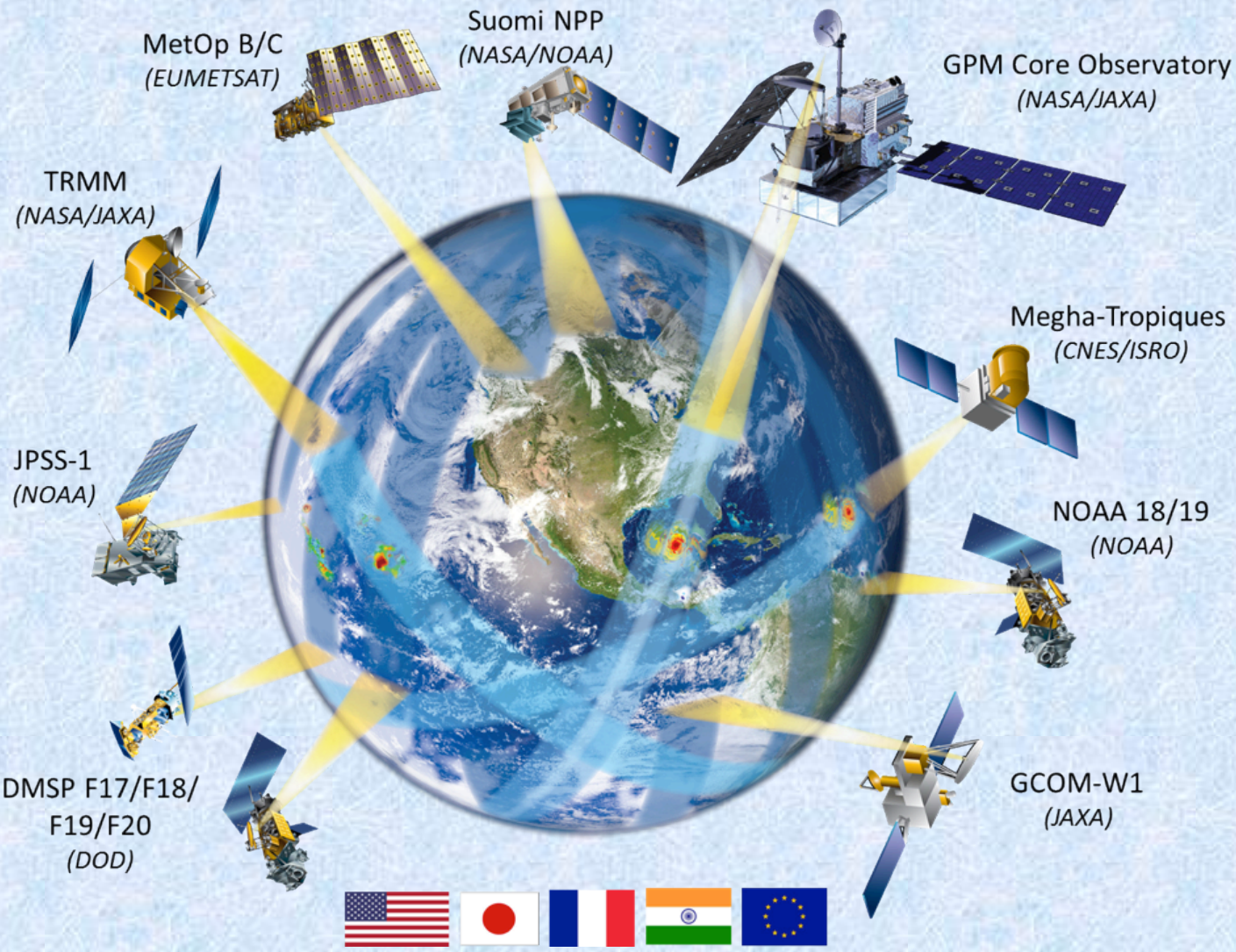
- Higher spatial resolution (IFOV: 6-26 km)
  - Improved light rain & snow detection
- Improved signals of solid precipitation over land (especially over snow-covered surfaces)
  - 4-point calibration to serve as a radiometeric reference for constellation radiometers



Combined Radar-Radiometer Retrieval

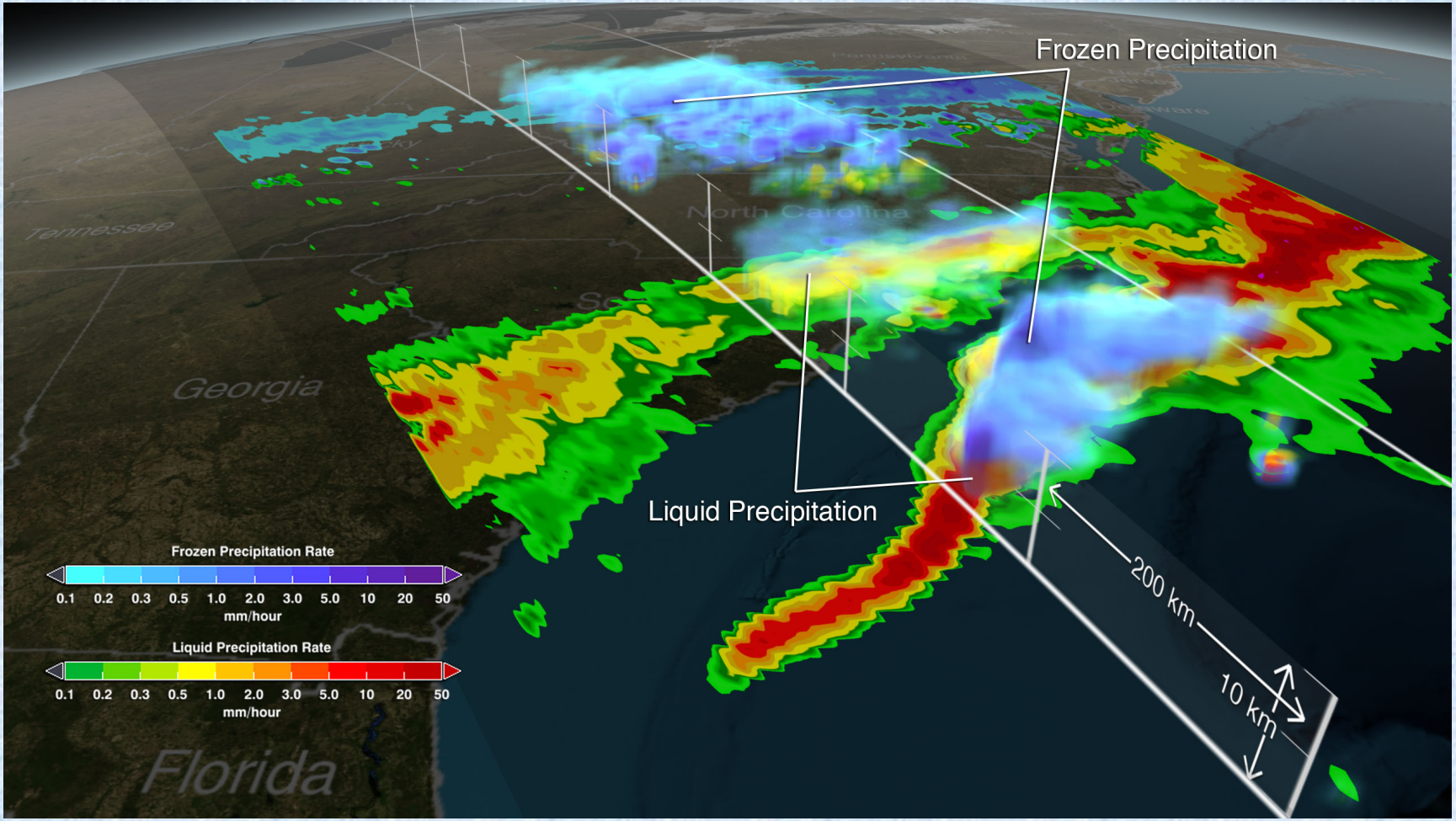
- DPR & GMI together provide greater constraints on possible solutions to improve retrieval accuracy
  - Observation-based a-priori cloud database for constellation radiometer retrievals

GPM's Global Scope



The GPM Core Observatory serves as an anchor to ensure that all constellation satellites produce uniform next-generation precipitation estimates everywhere in the world every three hours.

GPM Image of East Coast Snowstorm – 3/17/14

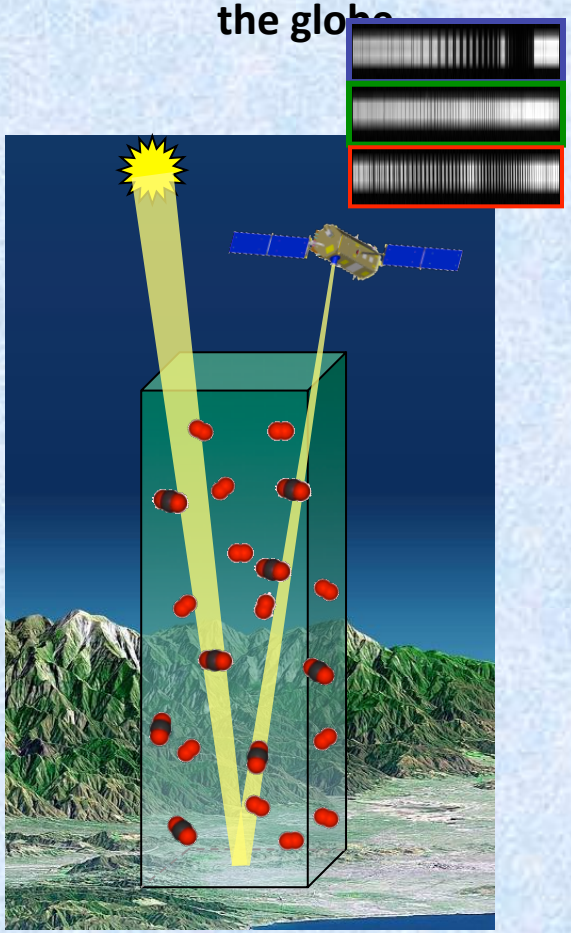


svs.gsfc.nasa.gov/cgi-bin/details.cgi?aid=4173

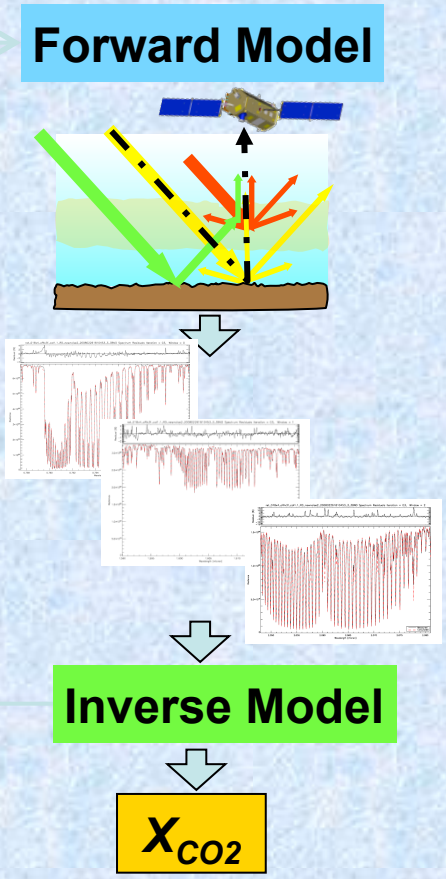
OCO-2 Launch – July 2, 2014

OCO-2 Measurement Approach

- **Collect spectra of CO_2 and O_2 absorption in reflected sunlight over the globe**

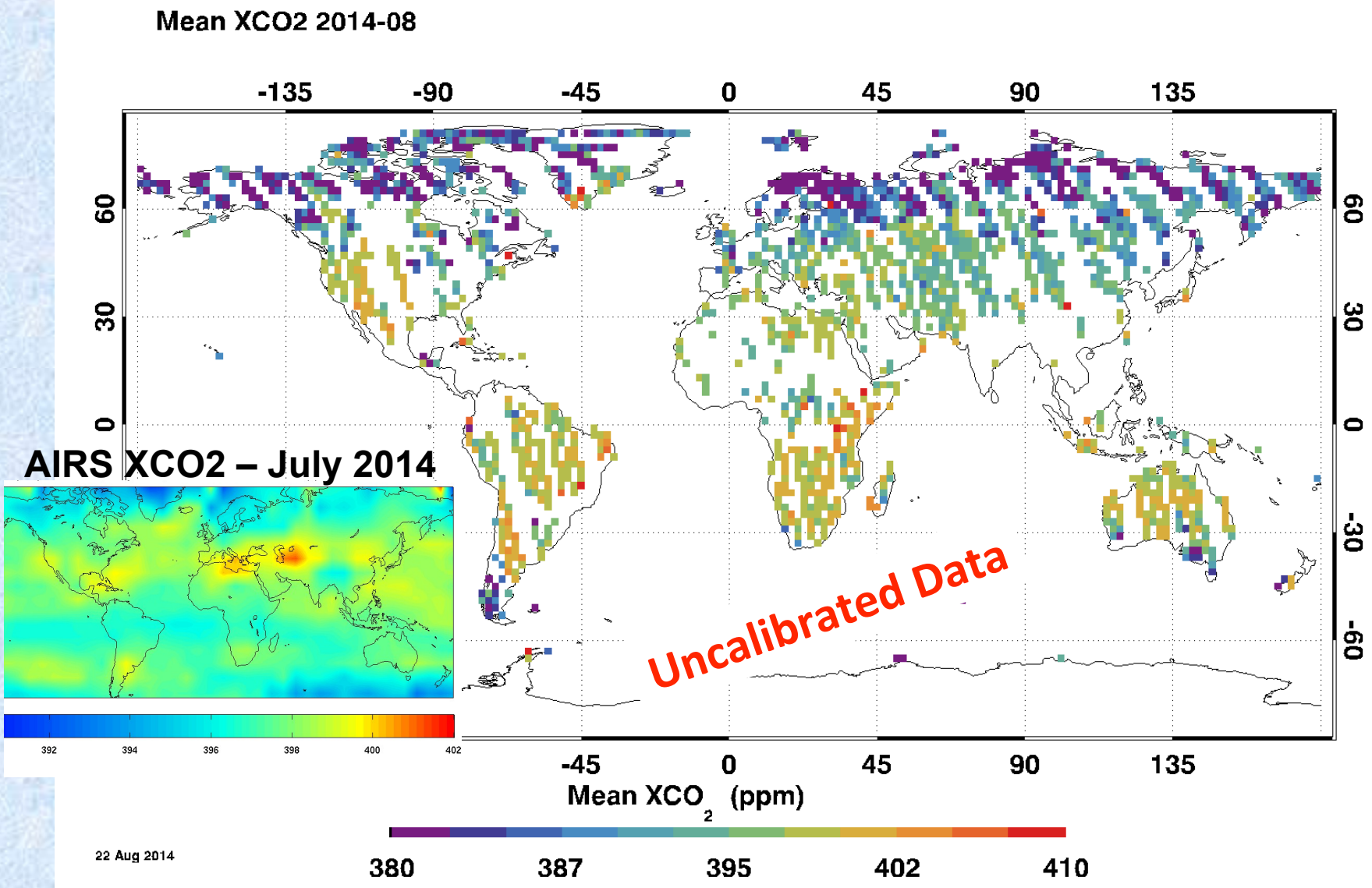


- **Retrieve** variations in the *column averaged CO_2 mixing ratio* over The sunlit hemisphere



- **Validate measurements to ensure CO_2 accuracy of 1 - 2 ppm (0.3 - 0.5%)**

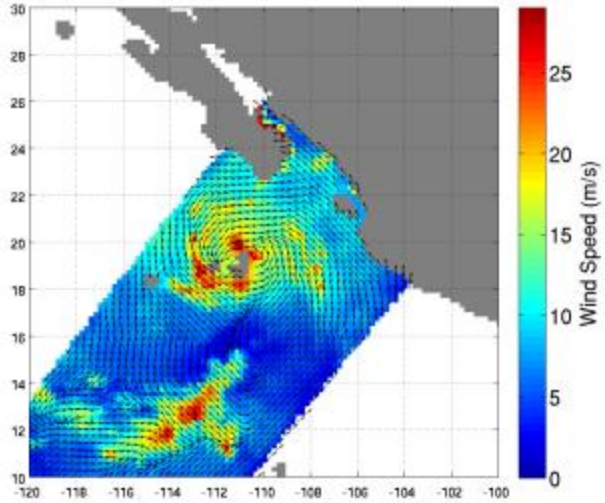
Orbiting Carbon Observatory-2 Mission
(August 2014, Instrument Checkout Period)



Preliminary XCO2 retrievals validate OCO-2 processing system and show anticipated results.

International Space Station-Rapid Scatterometer, or ISS-RapidScat

- NASA's newest Earth observing mission, the International Space Station-Rapid Scatterometer, or ISS-RapidScat, is collecting its first science data on ocean wind speeds and direction following its successful installation and activation on the exterior of the station's Columbus module.
- RapidScat will boost global monitoring of ocean winds for improved weather and marine forecasting, including hurricane monitoring, as well as climate studies. From the unique vantage point of the space station, this space-based scatterometer instrument will use radar pulses reflected from the ocean's surface from different angles to calculate ocean surface wind speeds and directions.
- The ISS-RapidScat instrument is a speedy and cost-effective replacement for NASA's former QuikScat Earth satellite, which monitored ocean winds to provide essential measurements used in weather predictions, including hurricane monitoring.



This image shows Tropical Storm Simon as seen by ISS-RapidScat as the storm approached Mexico's Baja California peninsula at 7:10 p.m. PDT on Oct. 3. Wind speeds are shown in color, with reds and yellows indicating the highest wind speeds. Wind directions are shown as arrows. Image credit: NASA-JPL/Caltech

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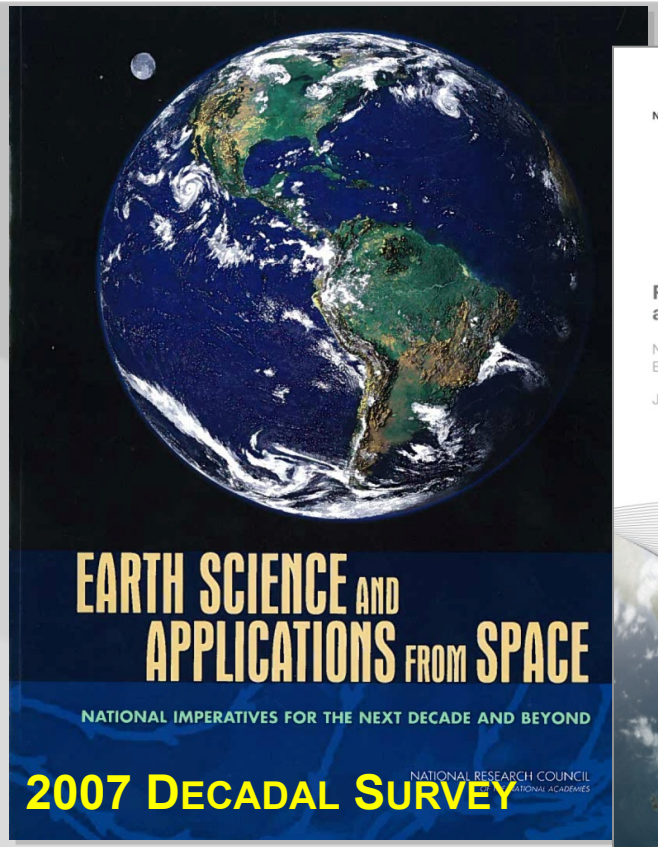
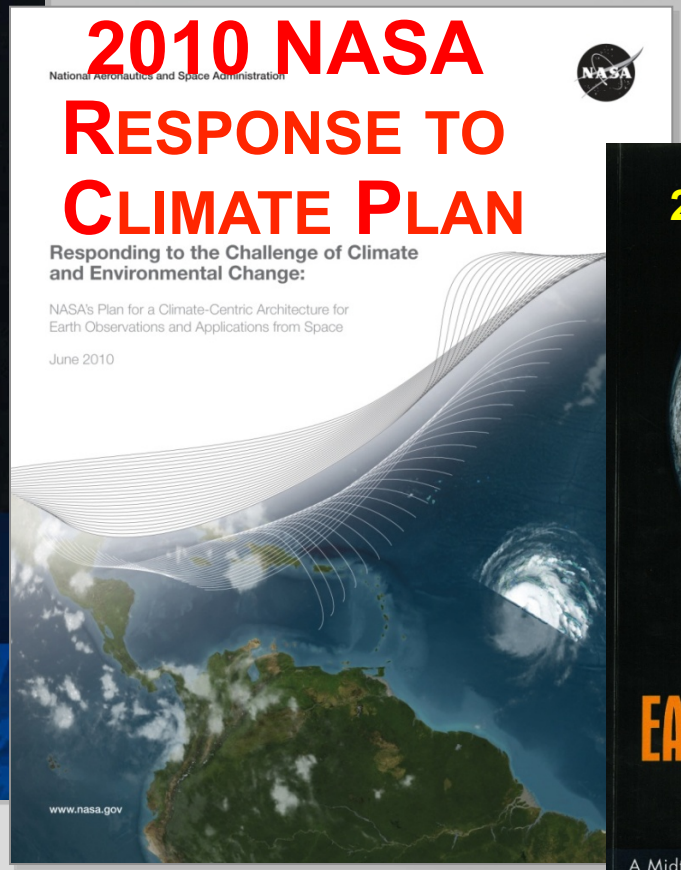
Guiding NASA Recommendation Documents

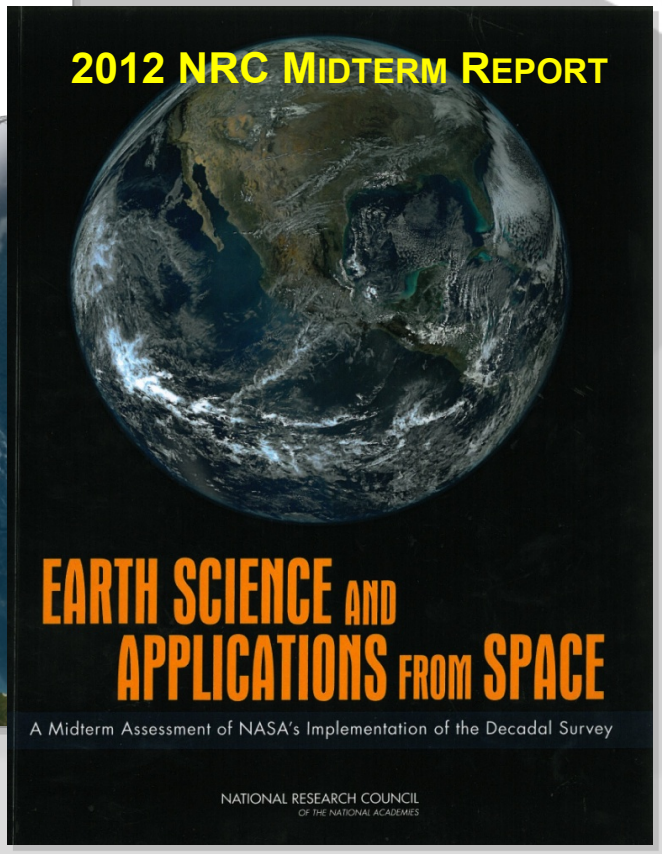


2007 Decadal Survey

- Research/Applications priorities
- No realistic budget constraint
- Shopping list of missions & activities
- Assumed Legacy missions completed



- Identified Continuity Measurements and Administration priorities
- Consistent with President's FY11 budget and realistic cost estimates
- Evaluated and endorsed by 13-agency USGCRP



- Endorsed NASA's progress in missions and non-flight activities
- Encouraged rigorous cost control

NRC Decadal Survey Recommended Missions

Decadal Survey Mission:	Mission Description	Orbit	Instruments
CLARREO (NASA portion)	Solar and Earth radiation: spectrally resolved forcing and response of the climate system	LEO, Precessing	Absolute, spectrally-resolved interferometer
SMAP	Soil moisture and freeze/thaw for weather and water cycle processes	LEO, SSO	L-band radar L-band radiometer
ICESat-II	Ice sheet height changes for climate change diagnosis	LEO, Non-SSO	Laser altimeter
DESDynI	Surface and ice sheet deformation for understanding natural hazards and climate; vegetation structure for ecosystem health	LEO, SSO	L-band InSAR Laser altimeter

Tier 1 ↑ ↓ Tier 2 Tier 3 →

Decadal Survey Mission	Mission Description	Orbit	Instruments
HyspIRI	Land surface composition for agriculture and mineral characterization; vegetation types for ecosystem health	LEO, SSO	Hyperspectral spectrometer
ASCENDS	Day/night, all-latitude, all-season CO_2 column integrals for climate emissions	LEO, SSO	Multifrequency laser
SWOT	Ocean, lake, and river water levels for ocean and inland water dynamics	LEO, SSO	Ka-band wide swath radar C-band radar
GEO-CAPE	Atmospheric gas columns for air quality forecasts; ocean color for coastal ecosystem health and climate emissions	GEO	High and low spatial resolution hyperspectral imagers
ACE	Aerosol and cloud profiles for climate and water cycle; ocean color for open ocean biogeochemistry	LEO, SSO	Backscatter lidar Multiangle polarimeter Doppler radar

Decadal Survey Mission	Mission Description	Orbit	Instruments
LIST	Land surface topography for landslide hazards and water runoff	LEO, SSO	Laser altimeter
PATH	High frequency, all-weather temperature and humidity soundings for weather forecasting and SST*	GEO	MW array spectrometer
GRACE-II	High temporal resolution gravity fields for tracking large-scale water movement	LEO, SSO	Microwave or laser ranging system
SCLP	Snow accumulation for fresh water availability	LEO, SSO	Ku and X-band radars K and Ka-band radiometers
GACM	Ozone and related gases for intercontinental air quality and stratospheric ozone layer prediction	LEO, SSO	UV spectrometer IR spectrometer Microwave limb sounder
3D-Winds (Demo)	Tropospheric winds for weather forecasting and pollution transport	LEO, SSO	Doppler lidar

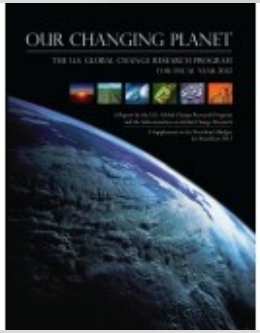
ESD's Interagency Coordination Efforts

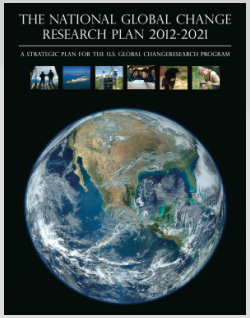
National Science And Technology Council (NSTC)

Committee on Environment, Natural Resources and Sustainability (CENRS)

Subcommittee on Global Change Research (SGCR)

U.S. Global Change Research Program (USGCRP)

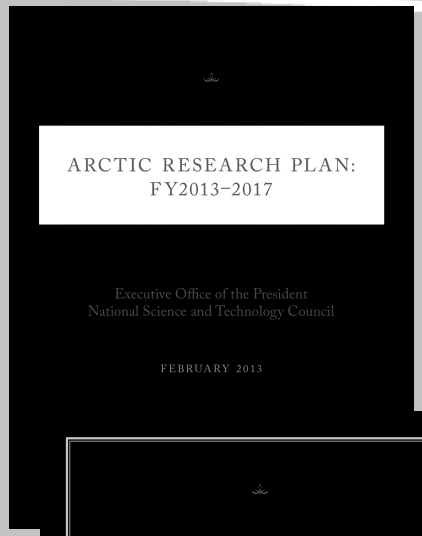


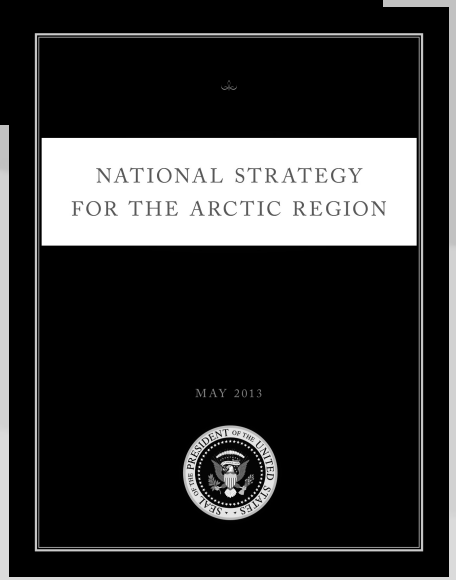


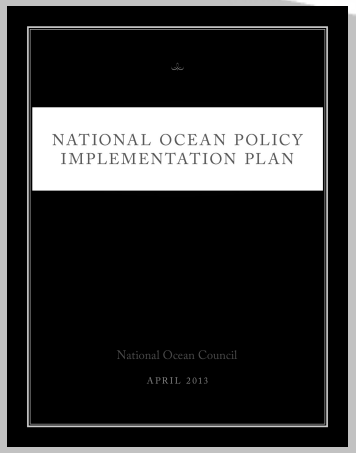
CENRS Sub-Committees, WGs, & Task Forces

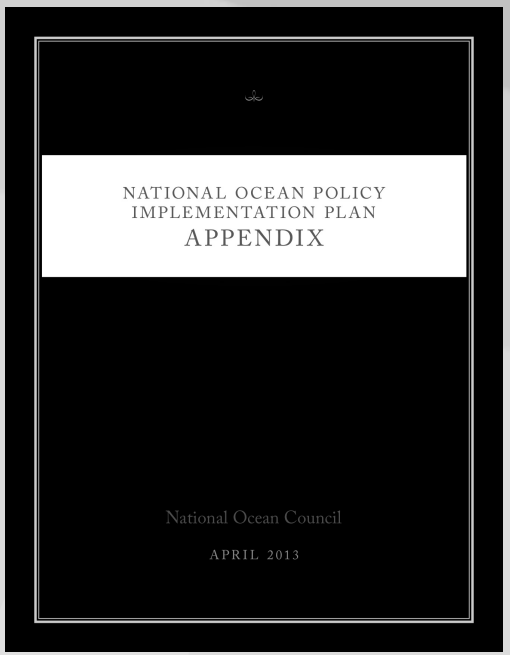
- Air Quality Research (AQRS)
- Critical and Strategic Mineral Supply Chains (CSMSC)
- **Interagency Arctic Research Policy Committee Interagency Working Group (IARPC)**
- Integration of Science and Technology for Sustainability Task Force
- National Earth Observations Task Force (NEO)
- Disaster Reduction (SDR)
- Ecological Services (SES)
- **Global Change Research (SGCR)**
- **Ocean Science & Technology (SOST)**
- Water Availability & Quality (SWAQ)
- Toxics & Risks (T&R)
- US Group on Earth Observations (USGEO)

Recent Interagency Plans …









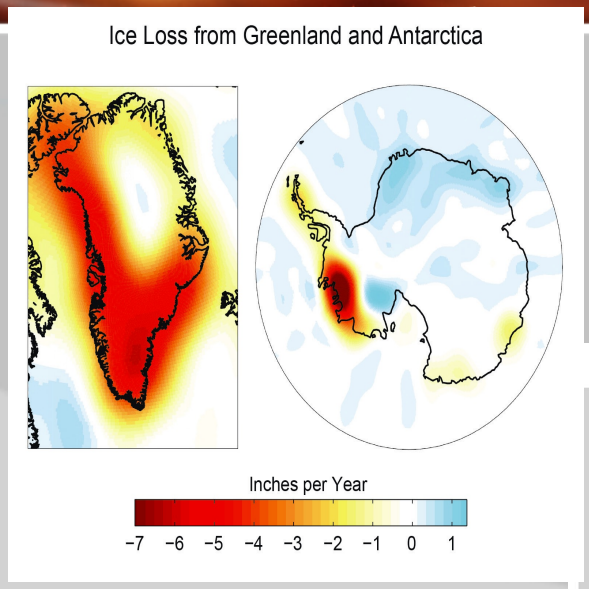
The USGCRP Vision and Mission

Vision - "A nation, globally engaged and guided by science, meeting the challenges of climate and global change."

Mission - "To build a knowledge base that informs human responses to climate and global change through coordinated and integrated federal programs of research, education, communication, and decision support."

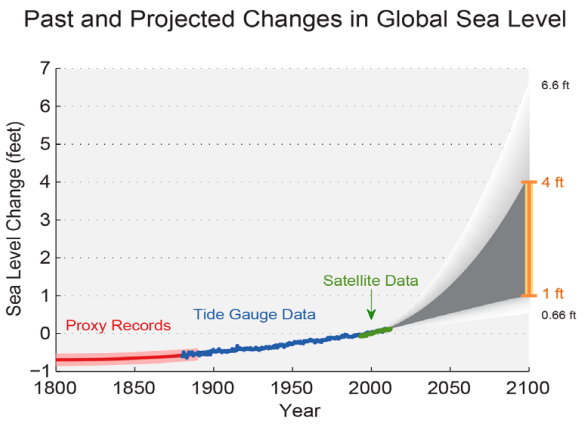
Goals	Objectives
1. Advance Science	1.1 Earth System Understanding 1.2 Science for Adaptation and Mitigation 1.3 Integrated Observations 1.4 Integrated Modeling 1.5 Information Management and Sharing
2. Inform Decisions	2.1 Inform Adaptation Decisions 2.2 Inform Mitigation Decisions 2.3 Enhance Global Change Information
3. Conduct Sustained Assessments	3.1 Scientific Integration 3.2 Ongoing Capacity 3.3 Inform Responses 3.4 Evaluate Progress
4. Communicate & Educate	4.1 Strengthen Communication and Education Research 4.2 Reach Diverse Audiences 4.3 Increase Engagement 4.4 Cultivate Scientific Workforce

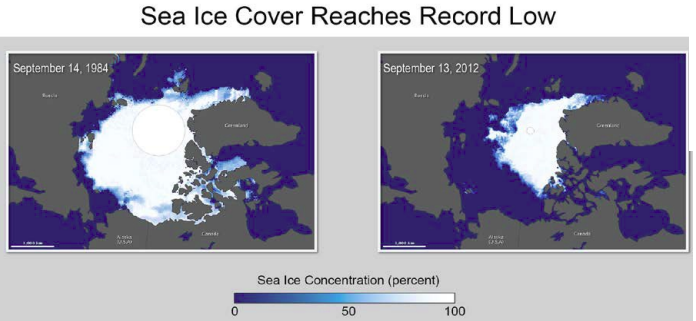
NASA in the NCA Report

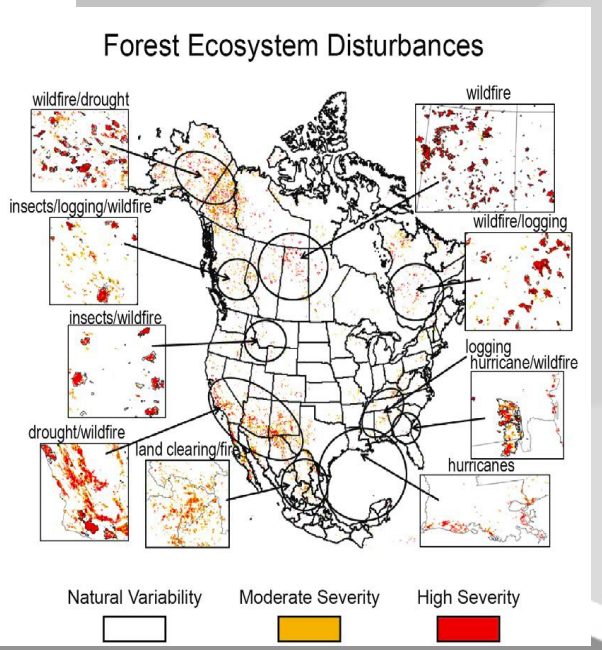


Chapter 2: Our Changing Climate

Appendix 3: Climate Science



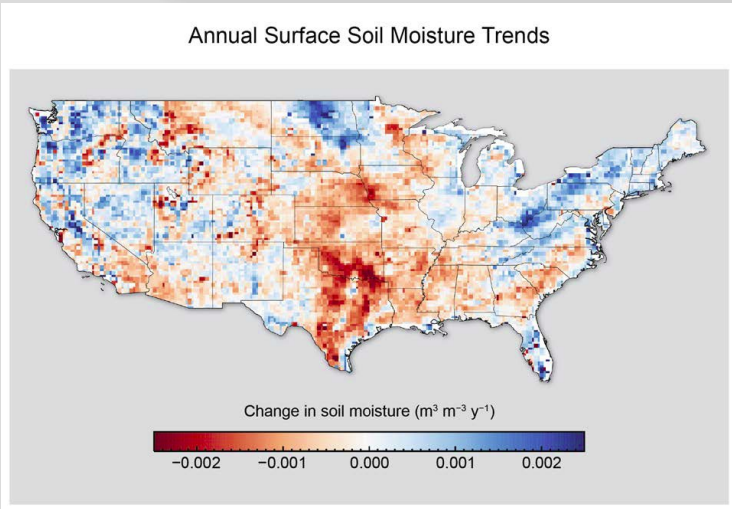




Chapter 12: Indigenous Peoples

Chapter 7: Forests

Chapter 3: Water Resources



The International Effort in Satellites and Global Observations for Climate

- Space-based perspective provides unequalled vantage point for observing entire Earth system
- Efforts of all countries are needed to provide needed breadth, resilience, and innovation
- Cooperation among nations, including data sharing calibration/validation, and assessment, enhances value of all nations' efforts
- Satellite data can support both long-term climate and near-term operational requirements, and be used to improve quality of life for all the world's citizens
- Numerous entities and mechanisms exist that are facilitating this coordination

CEOS Committee on Earth Observation Satellites

GEO GROUP ON EARTH OBSERVATIONS

GCOS

CGMS COORDINATION GROUP FOR METEOROLOGICAL SATELLITES

World Meteorological Organization
Working together in weather, climate and water

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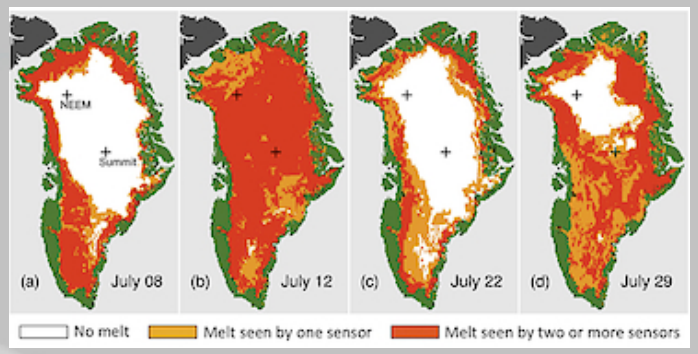
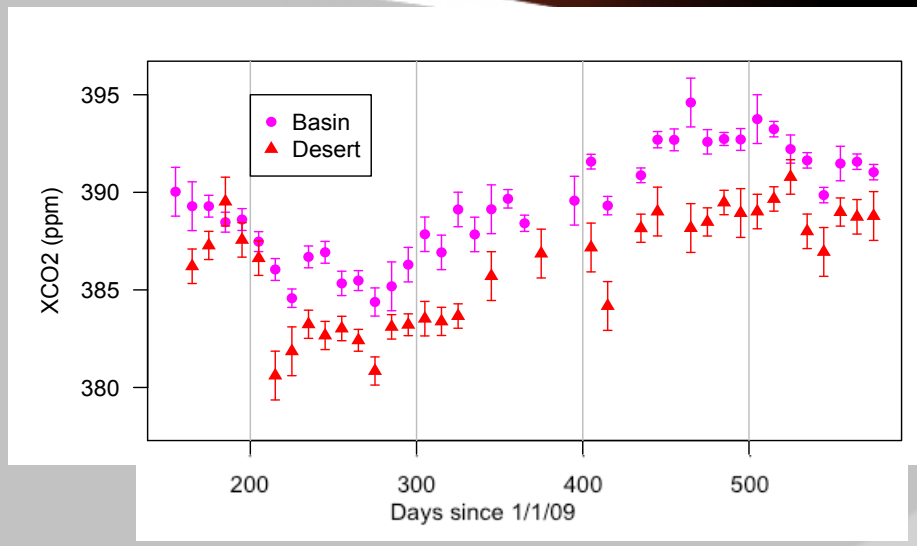
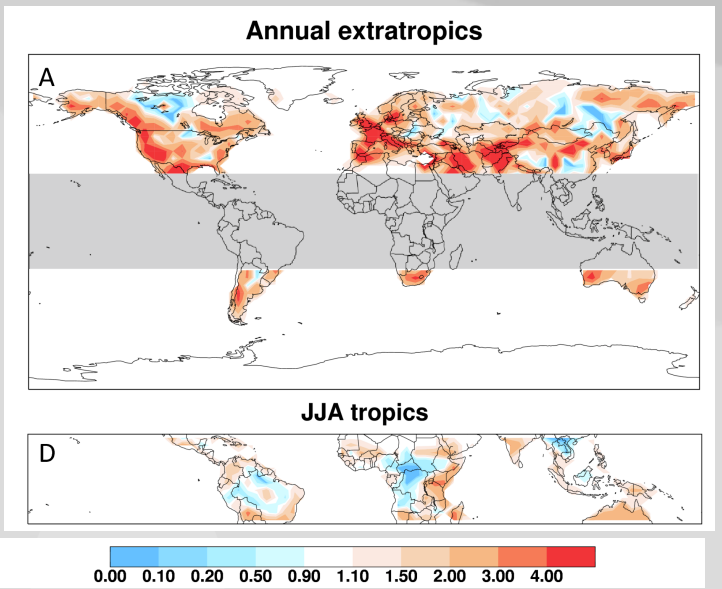
Selected Results from NASA Earth Observing Satellites



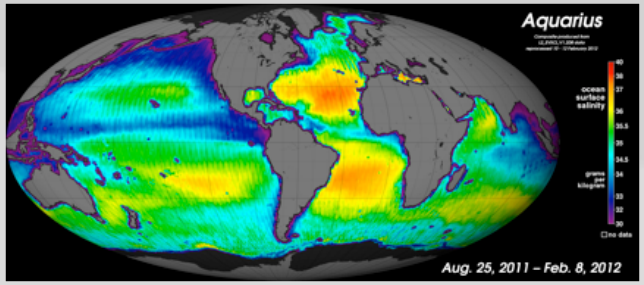
Composite maps of melt extent from OS2, SSMIS, and MODIS satellite data for: (a) 8 July, (b) 12 July, (c) 22 July, and (d) 29 July 2012.



First space-based detection of CO_2 enhancements over a megacity made using GOSAT (JAXA) observations & OCO algorithms

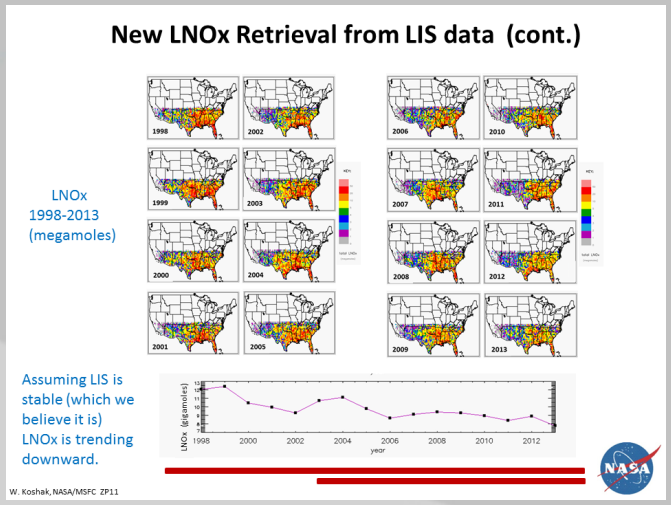


Global emissions of methanol inferred from TES instrument on Aura

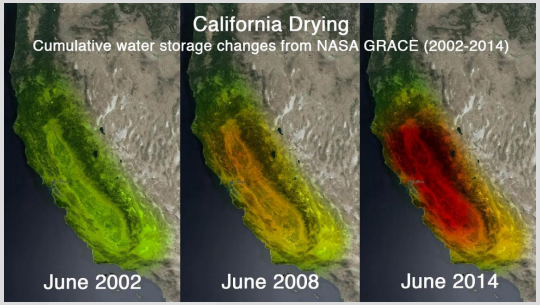


Globally averaged sea surface salinity measurements from Aquarius/SAC-D

More Recent Results



Results using TRMM/LIS data (flash optical energy estimates) show reduction in lightning-induced production of Nitrogen Oxides (NOx) in troposphere



GRACE data show loss of CA groundwater from 2002 to 2014

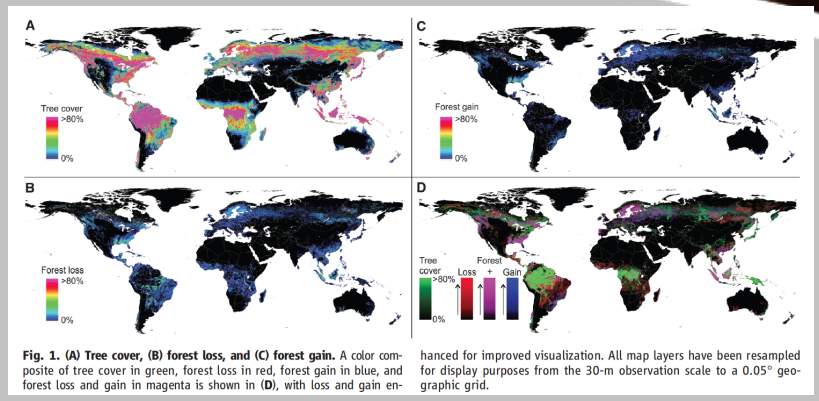


Fig. 1. (A) Tree cover, (B) forest loss, and (C) forest gain. A color composite of tree cover in green, forest loss in red, forest gain in blue, and forest loss and gain in magenta is shown in (**D**), with loss and gain enhanced for improved visualization. All map layers have been resampled for display purposes from the 30-m observation scale to a 0.05° geographic grid.

- The *first* high-resolution (30m) global map of forest cover change for 2000 – 2012 using data from Landsat, showing 2.3 million km^2 of forest were lost, 0.8 million km^2 of forest were gained, andd 0.2 million km^2 land experienced loss and subsequent gain

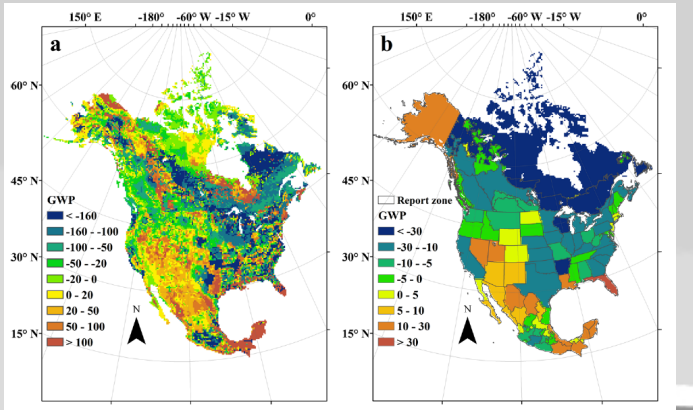
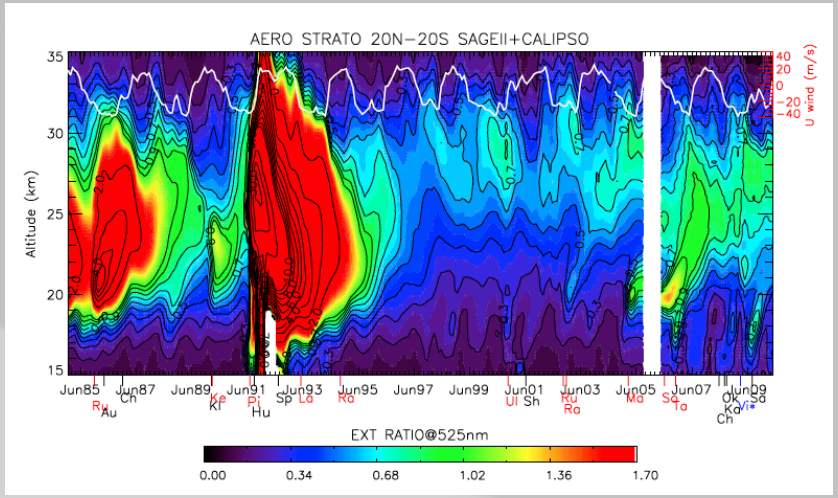
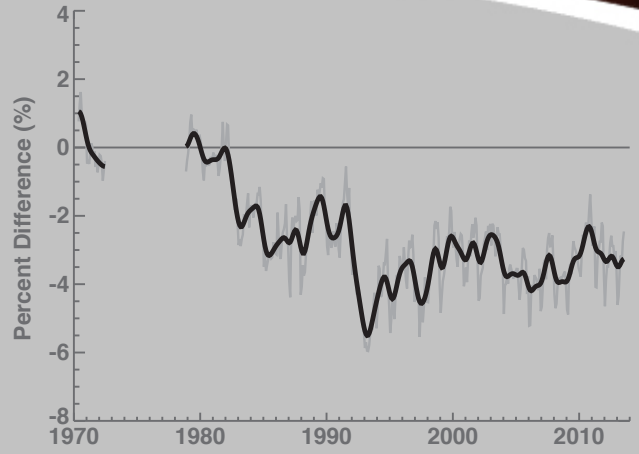


Fig. 3 Spatial patterns of combined global warming potential for CO_2, CH_4 and N_2O fluxes in North American terrestrial ecosystems during 2001–2010 (**a**: pixel level, unit: g CO_2 eq/m^2/year; **b**: reporting zones (delineated as Hayes et al. 2012, unit: Tg CO_2 eq/year/zone)

Model Results indicate North American Terrestrial CO_2 Uptake Largely Offset by CH_4 and N_2O Emissions - CH_4 and N_2O emissions offset an average of 73 (±14) % of the CO_2 sink.

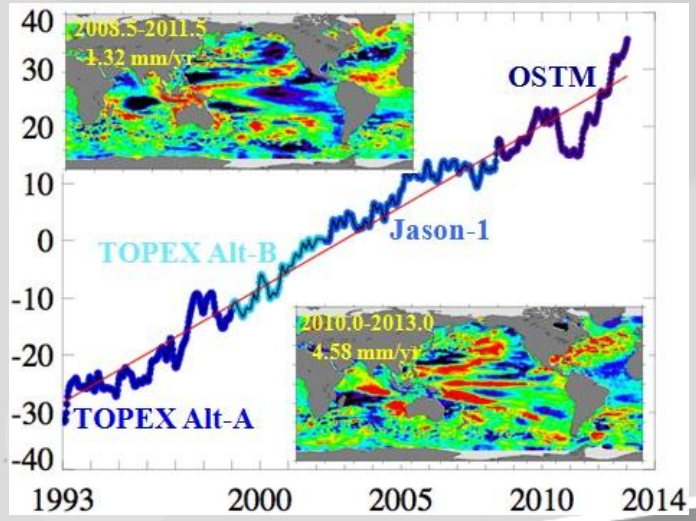
Long-Term Trends



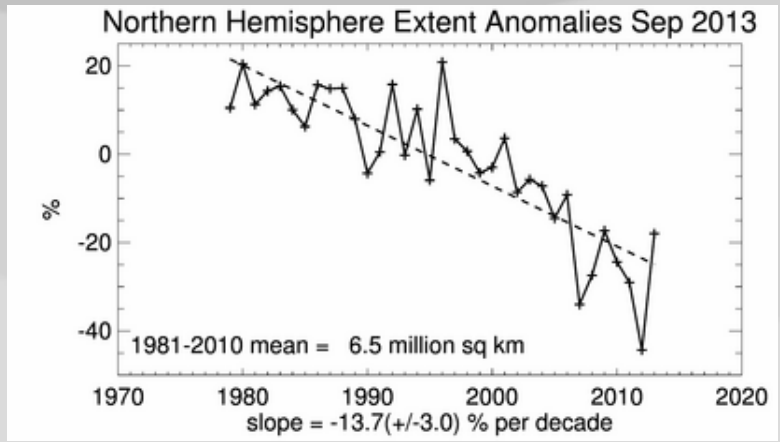


Stratospheric Ozone Trends

Long-Term Trends in Stratospheric Aerosols

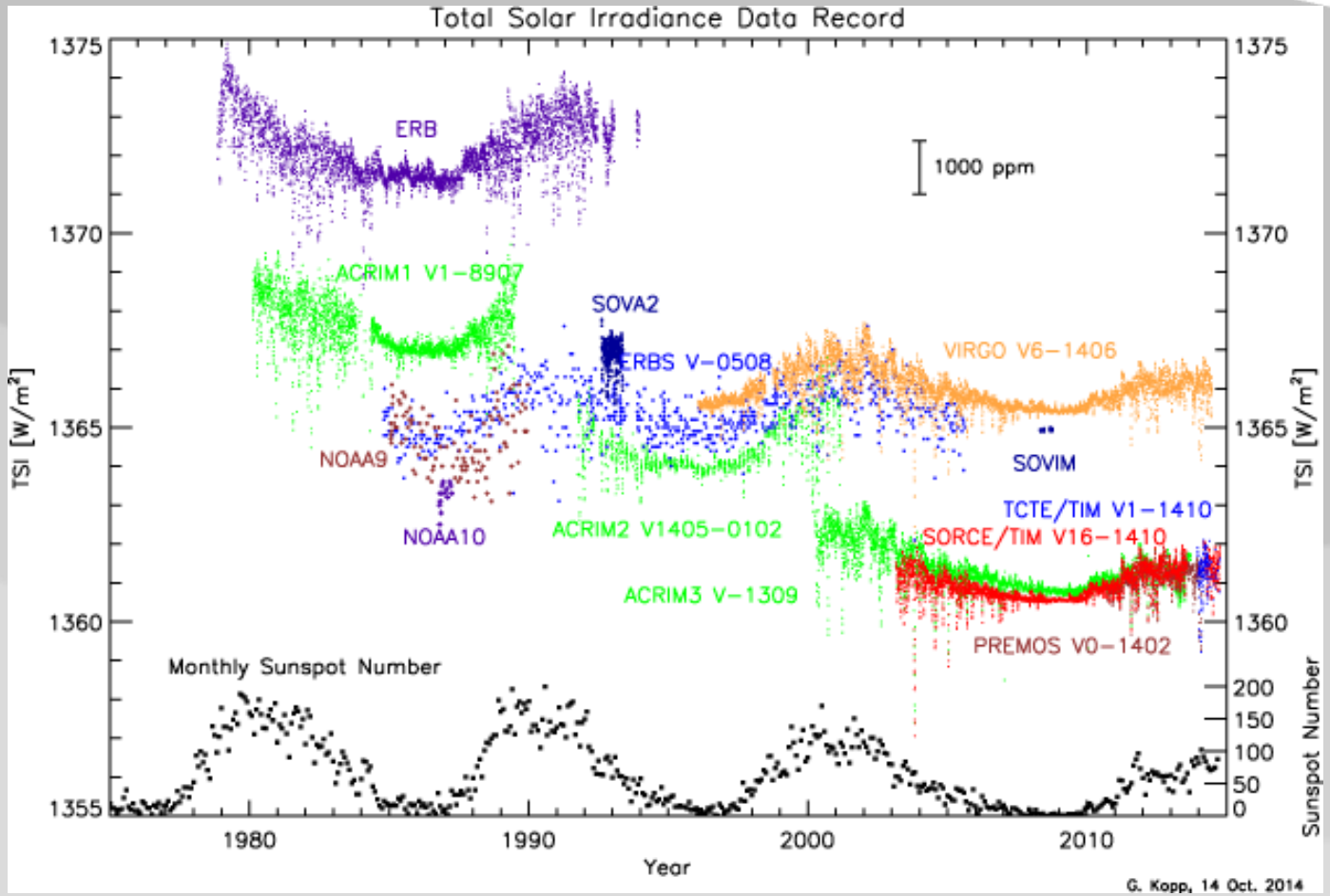


Global Sea Level Trend (and spatial variability)



Arctic Sea Ice Extent Changes

Total Solar Irradiance Record



NASA Observational Capability and "Phases" of Extreme Events

- NASA Satellites can observe all phases of extreme events and provide information to users (research, forecasting, response, …)
  - ✧ Background conditions/climatology against which extreme events may form
  - ✧ Development of extreme events
  - ✧ The event itself and its immediate impacts
  - ✧ Very near-term response (e.g., for disaster management
  - ✧ Longer term response (e.g., watching Earth system respond over seasons to years)
- Data tools provide access to data in real and/or near-real time (DB/DRL, LANCE)
- Research program supports longer-term analysis

Extreme Events can be anywhere … but we can see them!

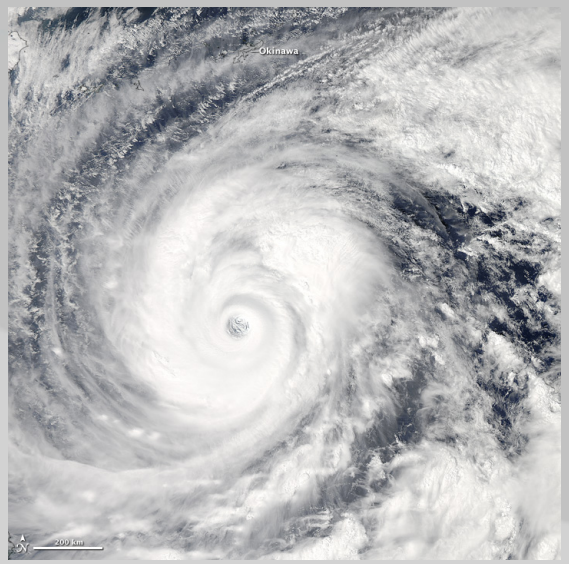
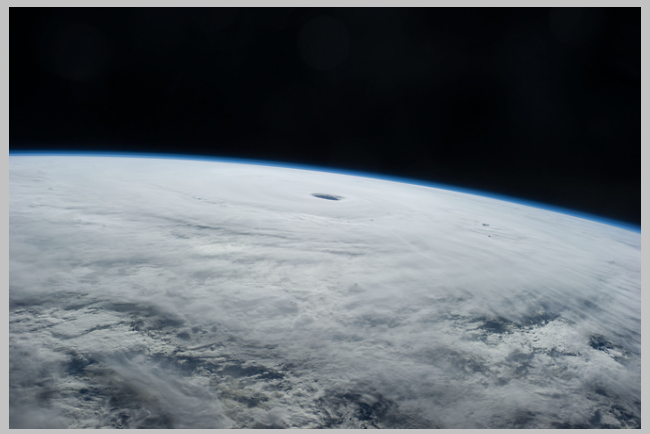
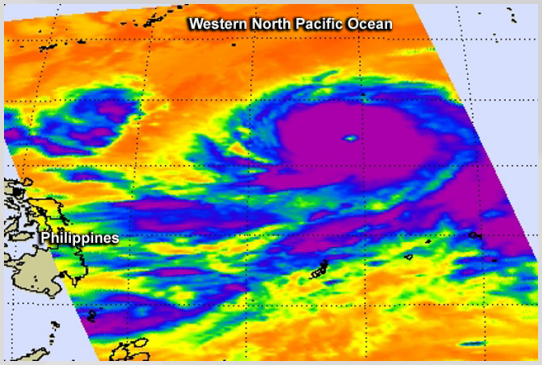


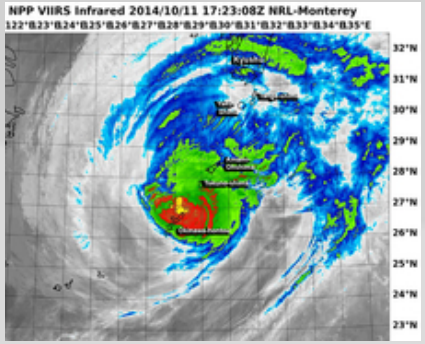
Image by Aqua/ MODIS 10/16/14



Photograph of Typhoon Vongfong taken from ISS on 10/9/14



AIRS image 10/9/14



Suomi-NPP VIIRS Image 10/11/14

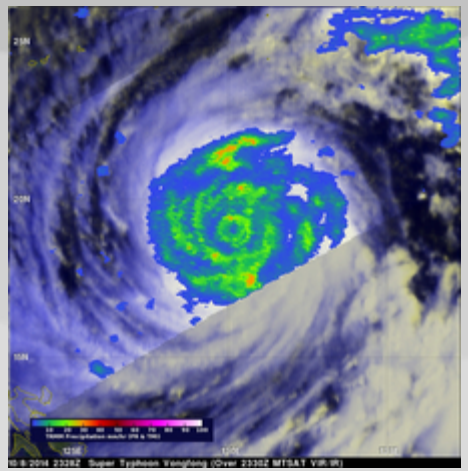


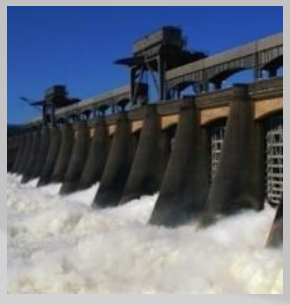
Image by TRMM 10/8/14

http://www.nasa.gov/content/goddard/tropical-storm-vongfong-nw-pacific-ocean/#.VEC1VN5PJ94

Applications Areas

Emphasis in 4 Applications Areas

Health & Air Quality



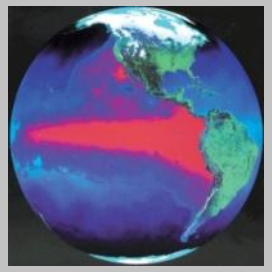
Water Resources

Disasters

Ecological Forecasting

Support opportunities in 5 additional areas

Agriculture



Climate

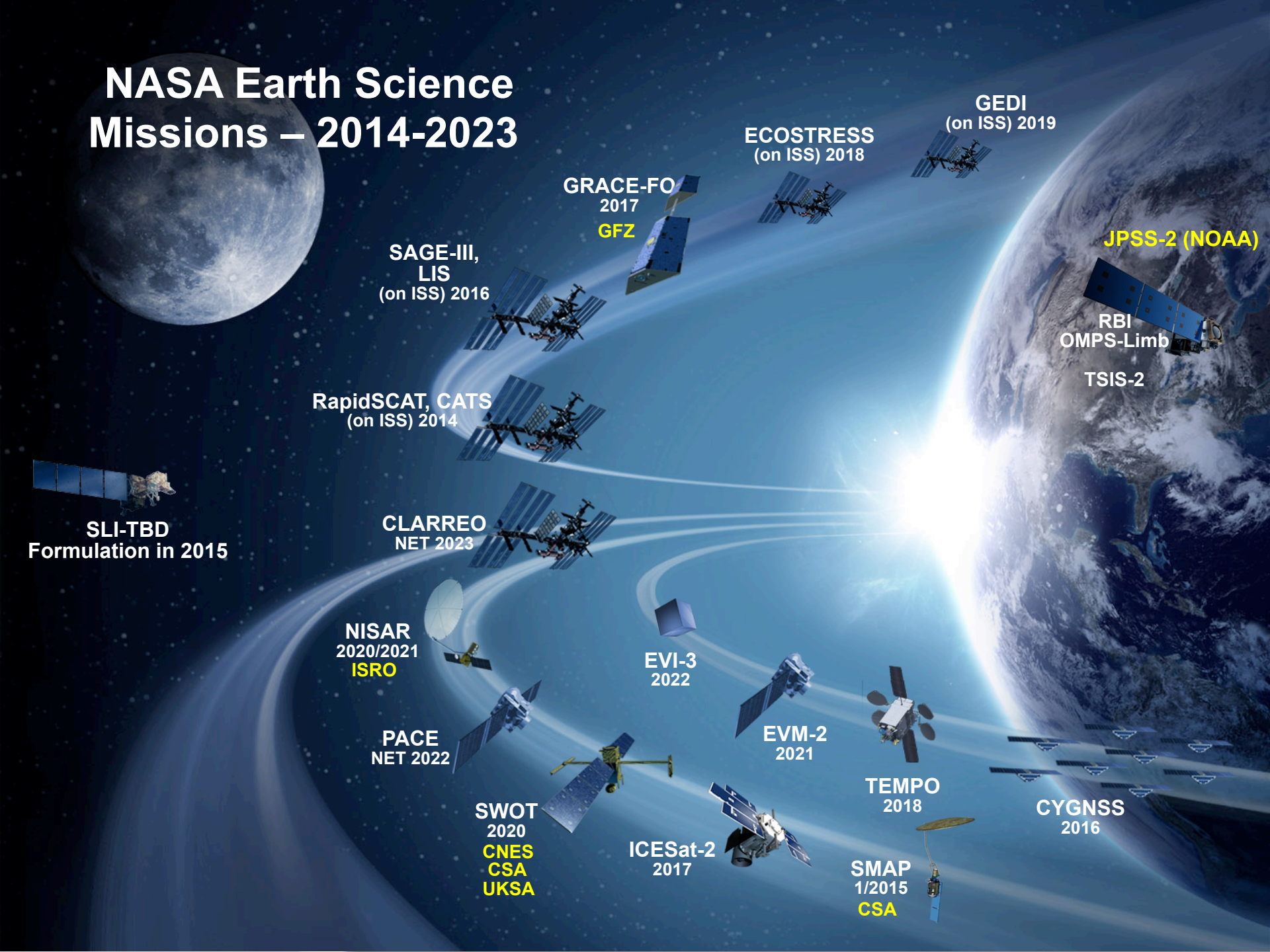
Weather

Energy

Oceans

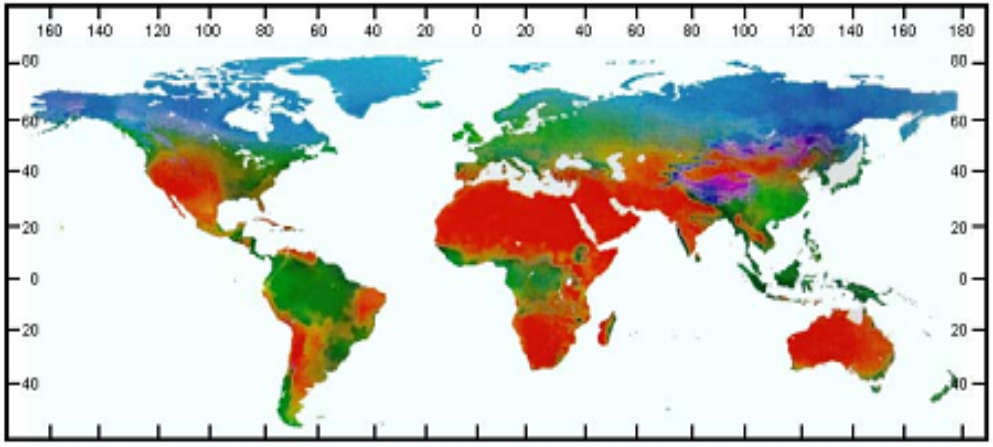
Overview of Talk

- Introduction – A Top Down View of the Earth
- How NASA Studies the Earth with Remote Sensing
- The Interagency and International Context
- What We're Learning
- Future Plans
- It's not ALL Satellites
- Some thoughts about the Future …
- Conclusion

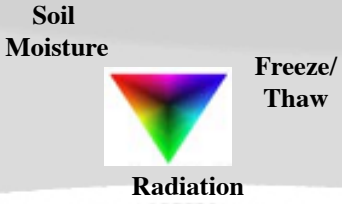

NASA Earth Science Missions – 2014-2023
GEDI (on ISS) 2019
ECOSTRESS (on ISS) 2018
GRACE-FO 2017 GFZ
SAGE-III, LIS (on ISS) 2016
JPSS-2 (NOAA)
RBI
OMPS-Limb
TSIS-2
RapidSCAT, CATS (on ISS) 2014
SLI-TBD Formulation in 2015
CLARREO NET 2023
NISAR 2020/2021 ISRO
EVI-3 2022
PACE NET 2022
EVM-2 2021
TEMPO 2018
CYGNSS 2016
SWOT 2020 CNES CSA UKSA
ICESat-2 2017
SMAP 1/2015 CSA

SMAP Science Objectives

- SMAP science objectives are to provide global mapping of soil moisture and freeze/thaw state (hydrosphere state) enabling science and applications users to:
  - Understand processes that link the terrestrial water, energy & carbon cycles
  - Estimate global water and energy fluxes at the land surface
  - Quantify net carbon flux in boreal landscapes
  - Enhance weather and climate forecast skill
  - Develop improved flood prediction and drought monitoring capability

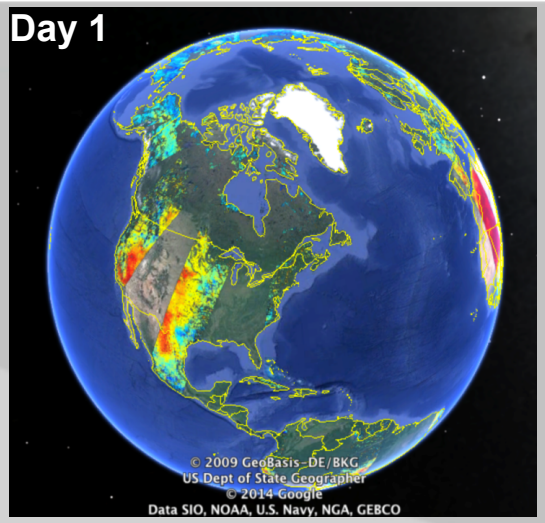


Primary Controls on Land Evaporation and Biosphere Primary Productivity

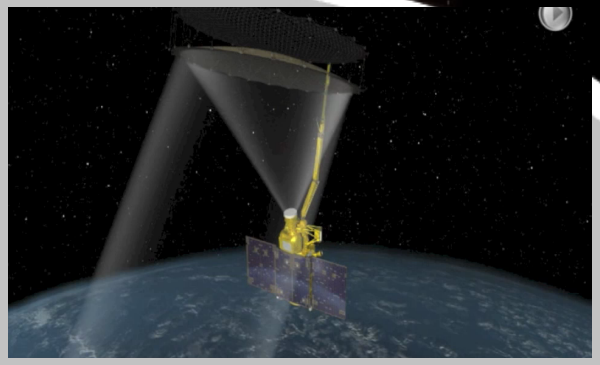


SMAP Soil Moisture Products

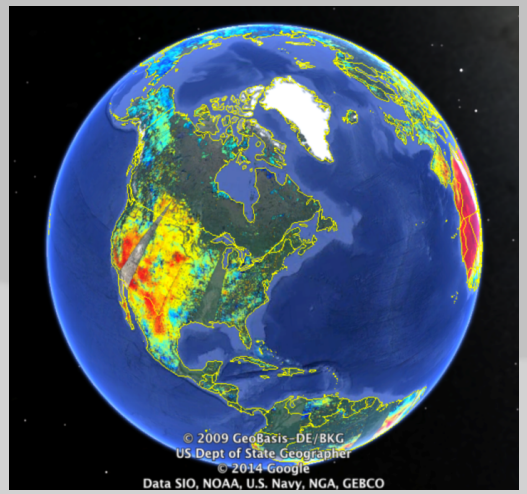
Day 1



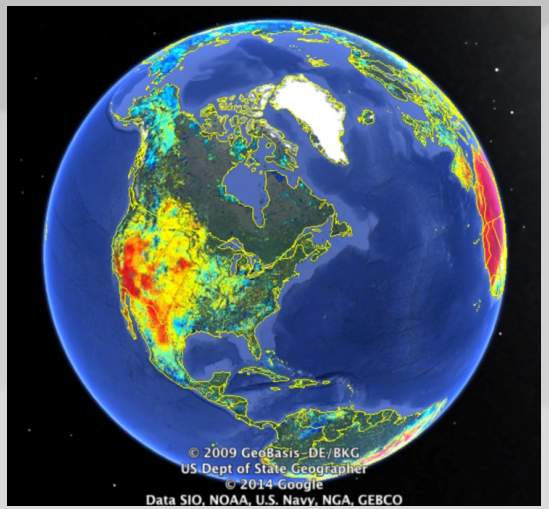
SMAP will provide moisture content measurement in the top 5 cm of soil at 10 km resolution globally every 3 days



Days 1+2



Days 1-3



SMAP measurements of soil moisture address a wide range of water cycle research and science applications, such as weather predictions, drought/flood monitoring, and food production. The illustrations provide the soil moisture color-coded with orange for dry conditions and blue for wet conditions.

Earth Science Missions & Applications

Early Adopters: *New with SMAP*

Purpose is to conduct pre-launch applications research to accelerate use of data after launch.

Organizations with clearly-defined needs for *SMAP*-like data products evaluate & demonstrate the utility of *SMAP* data for their application and decision making.

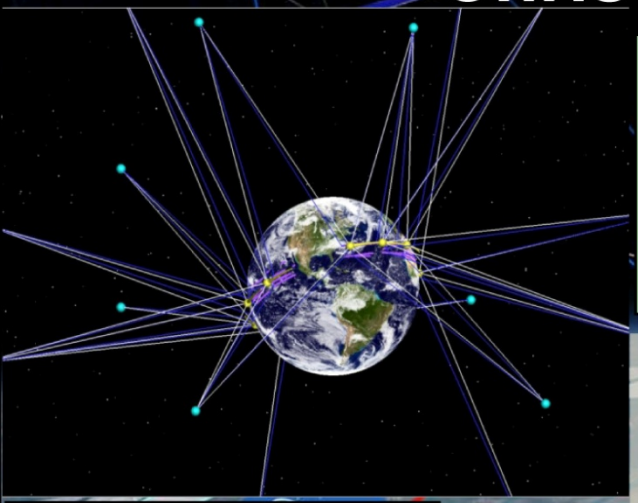
Early Adopters:

- Use data products prior to launch (simulated data and cal/val data from field campaigns)
- Provide feedback on products and formats to increase applications value of mission
- Streamline and accelerate use of data soon after launch and check-out
- Supply own resources to do these activities

25+ organizations are currently EAs from public & private-sector, domestic & foreign

CYclone Global Navigation Satellite System

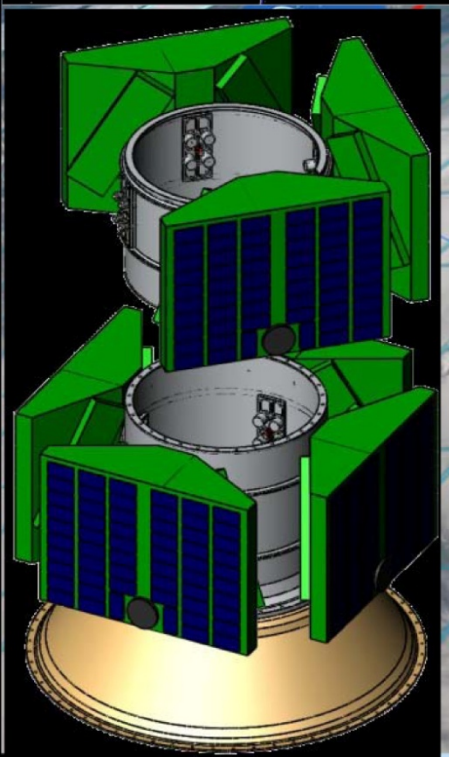
Chris Ruf, PI (U. Michigan)



CYGNSS is a constellation of 8 microsatellites that will use direct and reflected GPS signals to measure ocean surface wind speeds during most precipitation levels. This will increase the understanding of Tropical Cyclone genesis and intensification.

Primary Science Objectives

- **Measure ocean surface wind speed in almost all precipitating conditions including those in the Tropical Cyclone eyewall**
- **Measure ocean surface wind speed in the Tropical Cyclone inner core with sufficient frequency to resolve genesis and rapid intensification.**

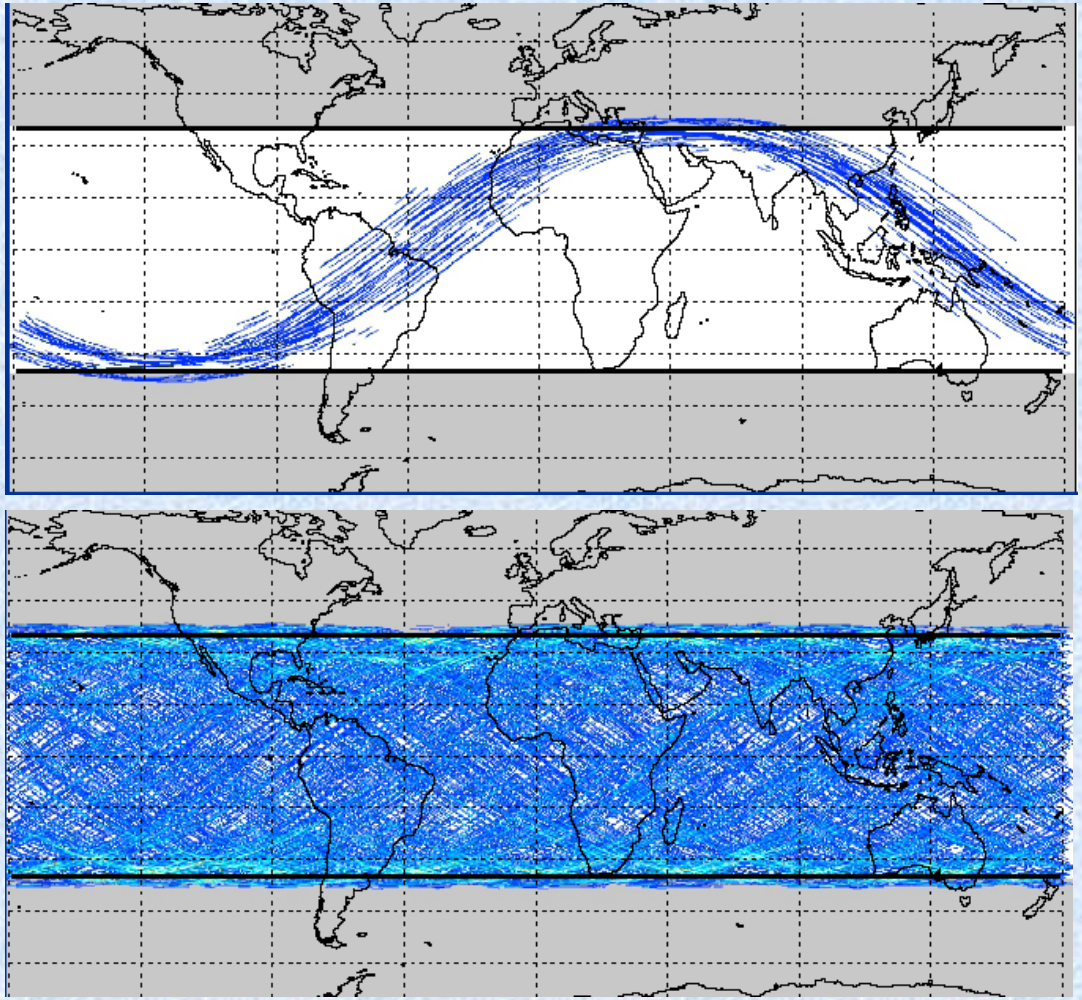


Partners	Southwest Research Institute: Primary Observatory development Surrey Satellite Technology, U.S.: Delay Doppler Mapping Instrument NASA Ames Research Center: Deployment Module
Risk	7120.5D Category 3; 8705.4 Payload Risk Class D
LRD	Target date February 2016
Orbit	35 deg inclination, 500 km altitude
Duration	2 year
Payload	Delay Doppler Mapping Instrument
LCC	$151.7M (RY$)

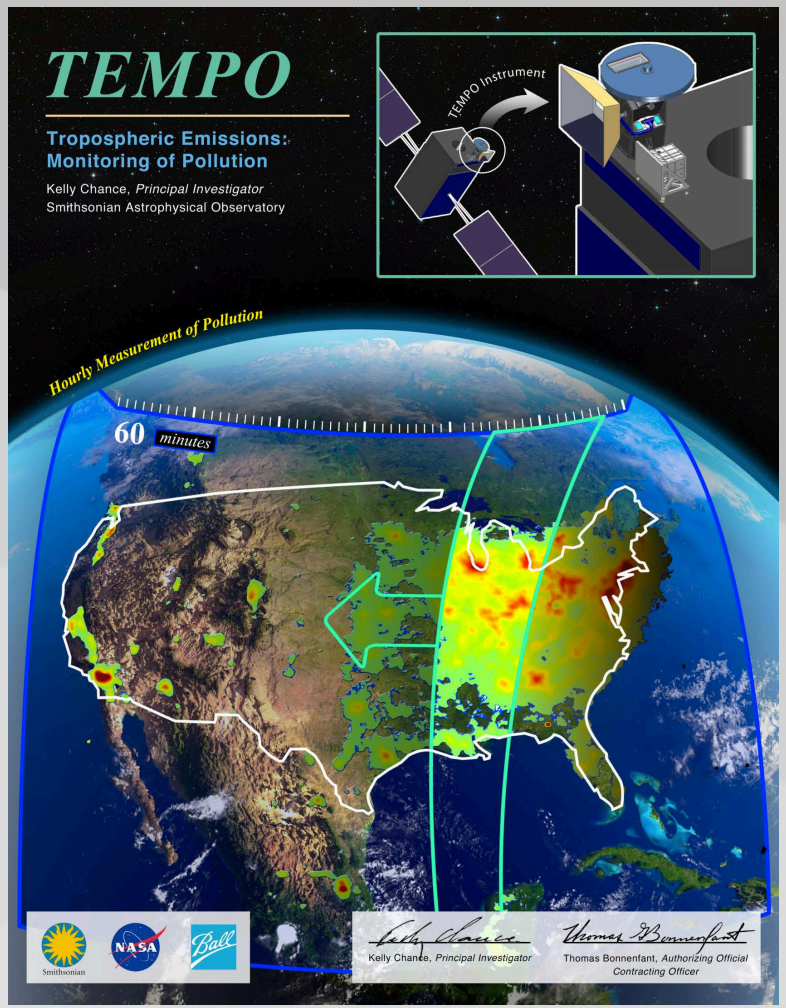
CYGNSS Temporal Sampling
(requirement is mean revisit time of 12 hr)

- Temporal sampling is not deterministic due to asynchronous CYGNSS and GPS orbits
- Model revisit time as a random variable with empirical pdf derived from Monte Carlo simulations
- (Top) 90 min (one orbit) coverage showing all specular reflection contacts by each of 8 s/c
- (Bottom) 24 hr coverage used to derive revisit pdf

- Median revisit time = 2.8 hr
- Mean revisit time = 5.9 hr

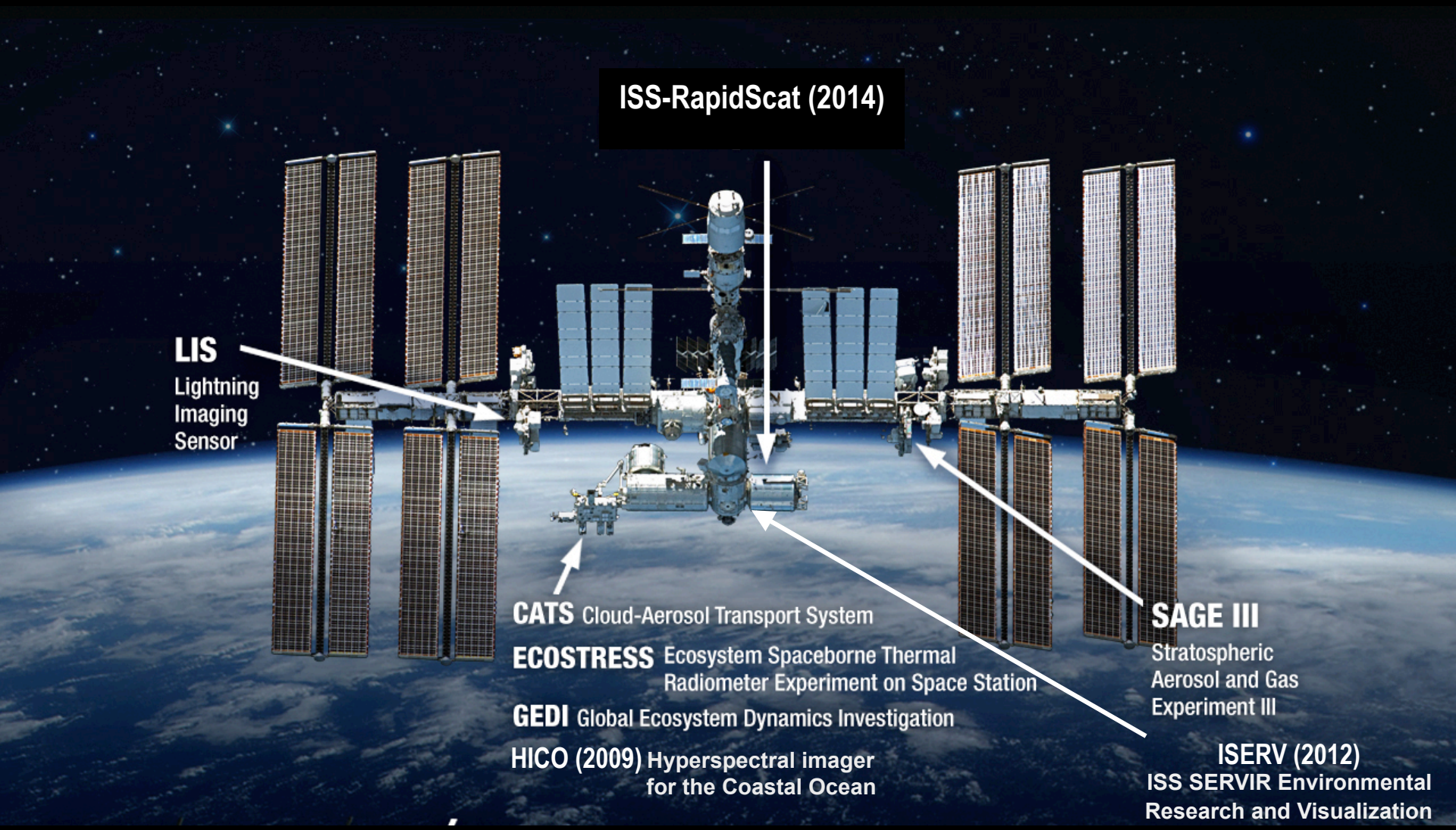


Newly Selected EV-I Mission – TEMPO for Geostationary Atmospheric Composition Measurements



- Tropospheric pollution observations from Geostationary Orbit using a UV and Visible Offner Grating spectrometer
  - It will retrieve Ozone, NO_2, SO_2, aerosols, CH_2O, among others.
- TEMPO will be simultaneous with, and complements related EU/GEMS Sentinel 4 and Korean GEO AQ observations, forming a global AQ constellation in GEO.
- Operational agencies like EPA and NOAA are part of the science team.
- TEMPO will be a pathfinder to using hosted commercial payloads from GEO

ISS Earth Observing Instruments



Future Implementation of Earth Science Observations from ISS

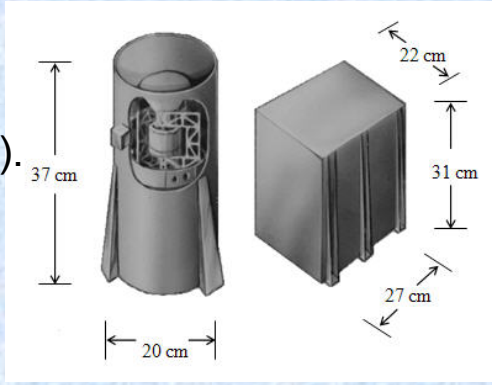
- **RapidSCAT** (2014)* [http://www.jpl.nasa.gov/missions/iss-rapidscat/] – to measure ocean surface wind speed and direction.
- **Cloud-Aerosol Transport System** (CATS) (2014)* [http://www.nasa.gov/mission_pages/station/research/experiments/1037.html] lidar system to measure location, composition and distribution of pollution, dust, smoke, aerosols and other particulates in the atmosphere. It will be mounted on the JEM-EF.
- **Stratosphere Aerosol and Gas Experiment III** (SAGE III) (2015) [http://sage.nasa.gov/SAGE3ISS/] – will measure vertical profiles of ozone, aerosols, and other atmospheric trace constituents – mounted to ISS aboard using an ESA-supplied Hexapod to the ExPRESS Logistics Carrier.
- **Lightning Imaging Sensor** (LIS) (2016)* [thunder.nsstc.nasa.gov/lis/] will continue the measurements of lightning (cloud-cloud and cloud-ground) in both daytime and nighttime initiated with LIS aboard TRMM (1997 launch) but with increased latitudinal coverage over TRMM (51.5 vs. 35 deg. Orbital inclination)

* Instrument funding provided by ISS Program

Lightning Imaging Sensor (LIS) on ISS

Mission Overview

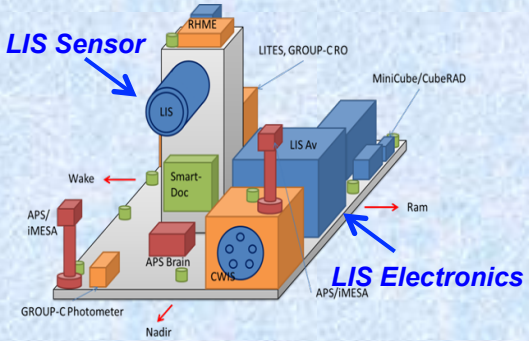
- NASA developed and demonstrated space-based lightning observation as a remote sensing tool under Earth Observing System (EOS) and Tropical Rainfall Measuring Mission (TRMM) (*LIS still operational on TRMM*).
- LIS on the ISS will extend TRMM time series observations, expand latitudinal coverage, and provide real time observations in support of important and pressing science and applications objectives.
- Integrate as hosted payload on DoD Space Test Program (STP-H5) and launch on SpaceX Dragon in January 2016 for 2-4 year mission.



LIS Sensor Head and Electronics Unit
(20 kg, 30W, 128x128 CCD, 1 kB/s)

Measurement

- **LIS measures global lightning** (***amount, rate, radiant energy***) during both day and night, with storm scale resolution, millisecond timing, and high, uniform detection efficiency.
  - LIS daytime detection is both unique and scientifically important (>70% occurs during day).
  - Only LIS globally detects TOTAL (*both cloud and ground*) lightning with no land-ocean bias.



STP-H5 (notional concept)

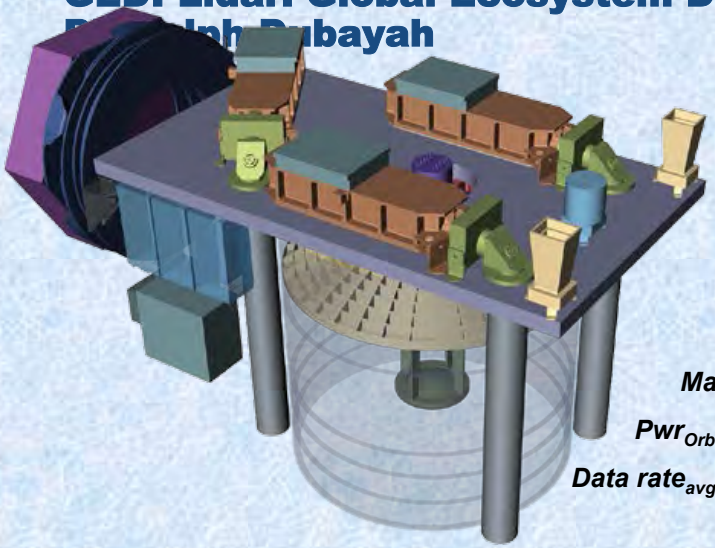
Science and Application Objectives

- **Lightning is quantitatively coupled to both thunderstorm and related geophysical processes.**
- Therefore lightning observations provide important gap-filling inputs to pressing Earth system sciences issues in a wide range of disciplines (e.g., *weather, climate, atmospheric chemistry, lightning physics*).
- **Real time observations will be provided to operational users.**
- **LIS data is the "Gold Standard" for global lightning climatology.**

Mission type: Class C, ISS

GEDI Lidar: Global Ecosystem Dynamics Investigation Lidar

Ralph Dubayah



Mass = 230 kg

$Pwr_{Orb\ Avg}$ = 516 W

$Data\ rate_{avg}$ = 2.1 Mbps

Mission:

GEDI will characterize the effects of changing climate and land use on ecosystem structure and dynamics, enabling improved understanding of Earth's carbon cycle and biodiversity. GEDI will provide the first global, high-resolution observations of forest vertical structure.

Goals:

GEDI will address the following questions:

- **What is the above-ground carbon balance of the land surface?**
- **What role will land surface play in mitigating atmospheric CO2?**
- **How does ecosystem structure affect habitat quality and biodiversity?**

GEDI measurements will quantify the following:

- **Distribution of above-ground carbon at fine spatial resolution**
- **Changes in carbon resulting from disturbance and subsequent recovery**
- **Spatial and temporal distribution of forest structure and its relationship to habitat quality and biodiversity**
- **Sequestration potential of forests over time w/changing land use, climate**

Instrument: Lidar

Mission & Science Team:

Principal Investigator: Ralph Dubayah, UMD
Project Manager: Kenneth Anderson, GSFC
Instrument System Engineer: Cheryl Salerno, GSFC
Deputy PI Instrument / Instrument Scientist: Bryan Blair, GSFC
Deputy PI Science: Scott Goetz, WHRC
Instrument Deputy Project Manager: Thomas Johnson, GSFC

Mission & Science Team:

University of Maryland, College Park
Goddard Space Flight Center
Woods Hole Research Center
US Forest Service
Brown University

Instrument Details:

- **Self-contained laser altimeter**
- **3 lasers are split into 7 beams dithered to produce 14 ground track spot beams.**
- **Beams have a 25 meter footprint and are spaced 500 m cross-track and 60 m along-track to produce fine grids of forest structure.**
- **70 cm diameter telescope/receiver.**
- **Detector has 75% transmission and 50% quantum efficiency.**
- **Si:APD detectors: Near-photon-noise limited, >500:1 dynamic range**
- **IFOV matched to contain return spot beams**
- **GPS, IMU, Star Trackers give precise ranging, attitude and position.**
- **A single-axis mechanism rotates the instrument about the roll axis, providing off-nadir pointing for global coverage.**
- **Canopy profile accurate to 1 m**
- **Geolocation < 10 m for plot calibration**
- **Biomass error < 20% at pixel level**

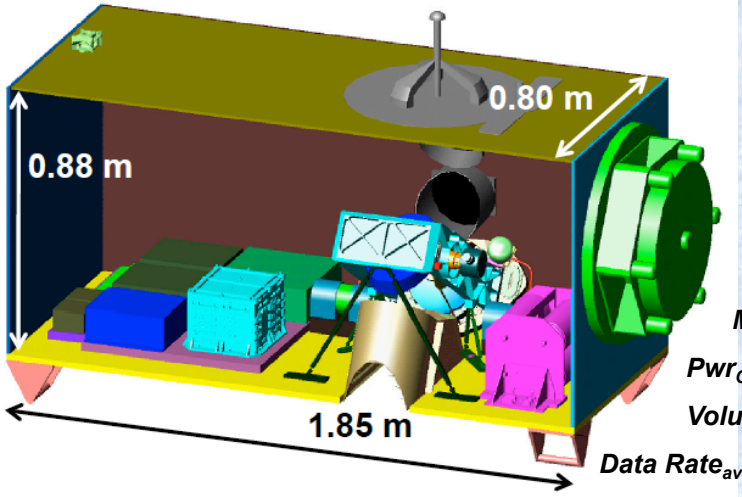
FY16 Cost: ~$94 M

Threshold: Acquire canopy vertical profile to estimate above-ground woody carbon density for vegetated areas at <1 km.

Mission type: Class D, ISS

ECOSTRESS: ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station

PI: Simon Hook



Mass = 266 kg

$Pwr_{Orb\ Avg}$ = 527 W

Volume = 1.30 m^3

$Data\ Rate_{avg}$ = 2.32 Mbps

Mission:

ECOSTRESS will provide the first high spatiotemporal resolution thermal infrared measurements of Earth's surface from ISS. Measurements at varying times over the diurnal cycle will reveal answers related to water stress in plants and how selected regions will respond to future climate changes.

Goals:

- **Identify critical thresholds of water use and water stress in key climate-sensitive biomes.**
- **Detect the timing, location, and predictive factors leading to plant water uptake decline and/or cessation over the diurnal cycle**
- **Measure agricultural water consumptive use over the contiguous United States (CONUS) at spatiotemporal scales applicable to improve drought estimation accuracy**

Instrument: Thermal infrared radiometer

Heritage: Prototype Hyperspectral Infrared Imager (HyspIRI) Thermal Infrared Radiometer (PHyTIR; a laboratory instrument); Algorithms: ASTER, MODIS.

Mission & Science Team:

Principal Investigator: Simon Hook, JPL

Project Manager: Thomas Glavich, JPL

Lead System Engineer: Marc Foote, JPL

Alternate Project Manager: Renaud Goullioud, JPL

Major Partners:

Jet Propulsion Laboratory

Instrument Details:

- **Cross-track whisk broom scanner**
- **Swath width: 384 km (51°)**
- **Spatial resolution: 38 m x 57 m (nadir) pixels**
- **Five thermal IR bands between 8.3 and 12.1 microns**
- **Noise equivalent delta temperature: ≤ 0.1 K**
- **Two COTS cryocoolers for 60 K focal plane**
- **Typical revisit of 90% of CONUS every 4 days at varying times over diurnal cycle**

FY16 Cost: ~$30M

Threshold: Same as baseline.

NRC Decadal Survey Recommended Missions

Decadal Survey Mission:	Mission Description	Orbit	Instruments
CLARREO (NASA portion)	Solar and Earth radiation: spectrally resolved forcing and response of the climate system	LEO, Precessing	Absolute, spectrally-resolved interferometer
SMAP	Soil moisture and freeze/thaw for weather and water cycle processes	LEO, SSO	L-band radar L-band radiometer
ICESat-II	Ice sheet height changes for climate change diagnosis	LEO, Non-SSO	Laser altimeter
DESDynI	Surface and ice sheet deformation for understanding natural hazards and climate; vegetation structure for ecosystem health	LEO, SSO	L-band InSAR Laser altimeter

Tier 1 ↑ ↓ Tier 2 Tier 3 →

Decadal Survey Mission	Mission Description	Orbit	Instruments
HyspIRI	Land surface composition for agriculture and mineral characterization; vegetation types for ecosystem health	LEO, SSO	Hyperspectral spectrometer
ASCENDS	Day/night, all-latitude, all-season CO_2 column integrals for climate emissions	LEO, SSO	Multifrequency laser
SWOT	Ocean, lake, and river water levels for ocean and inland water dynamics	LEO, SSO	Ka-band wide swath radar C-band radar
GEO-CAPE	Atmospheric gas columns for air quality forecasts; ocean color for coastal ecosystem health and climate emissions	GEO	High and low spatial resolution hyperspectral imagers
ACE	Aerosol and cloud profiles for climate and water cycle; ocean color for open ocean biogeochemistry	LEO, SSO	Backscatter lidar Multiangle polarimeter Doppler radar

Decadal Survey Mission	Mission Description	Orbit	Instruments
LIST	Land surface topography for landslide hazards and water runoff	LEO, SSO	Laser altimeter
PATH	High frequency, all-weather temperature and humidity soundings for weather forecasting and SST*	GEO	MW array spectrometer
GRACE-II	High temporal resolution gravity fields for tracking large-scale water movement	LEO, SSO	Microwave or laser ranging system
SCLP	Snow accumulation for fresh water availability	LEO, SSO	Ku and X-band radars K and Ka-band radiometers
GACM	Ozone and related gases for intercontinental air quality and stratospheric ozone layer prediction	LEO, SSO	UV spectrometer IR spectrometer Microwave limb sounder
3D-Winds (Demo)	Tropospheric winds for weather forecasting and pollution transport	LEO, SSO	Doppler lidar

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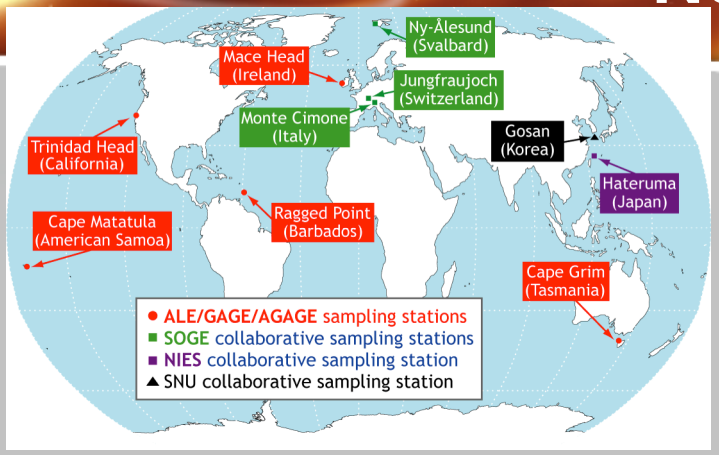
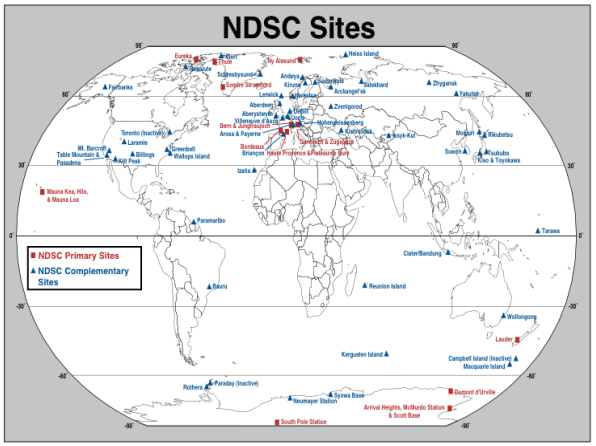
- How NASA Studies the Earth with Remote Sensing
- The Interagency and International Context
- What We're Learning
- Future Plans
- It's not ALL Satellites
- Some thoughts about the Future …
- Conclusion

Examples of NASA-Supported* Ground Networks

AGAGE

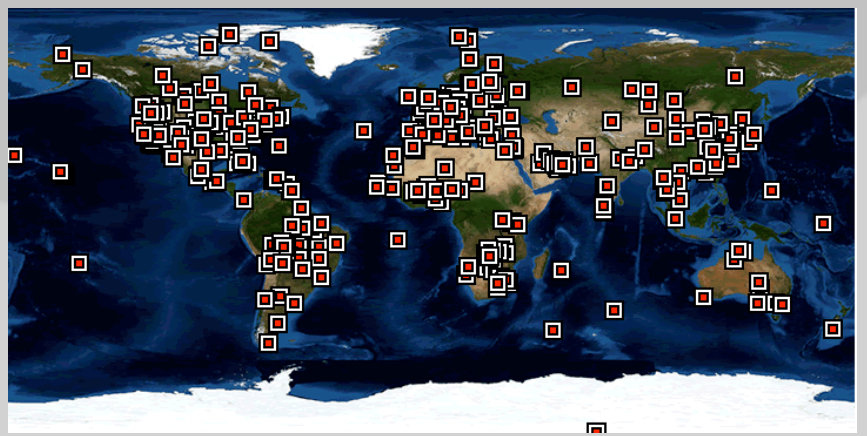


NDACC



ILRS

AERONET



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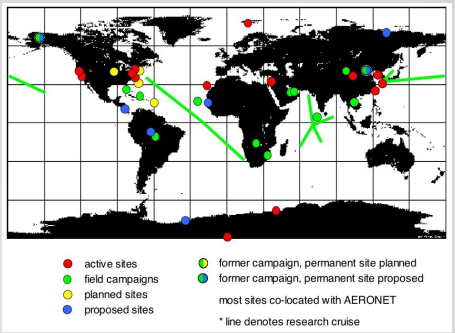
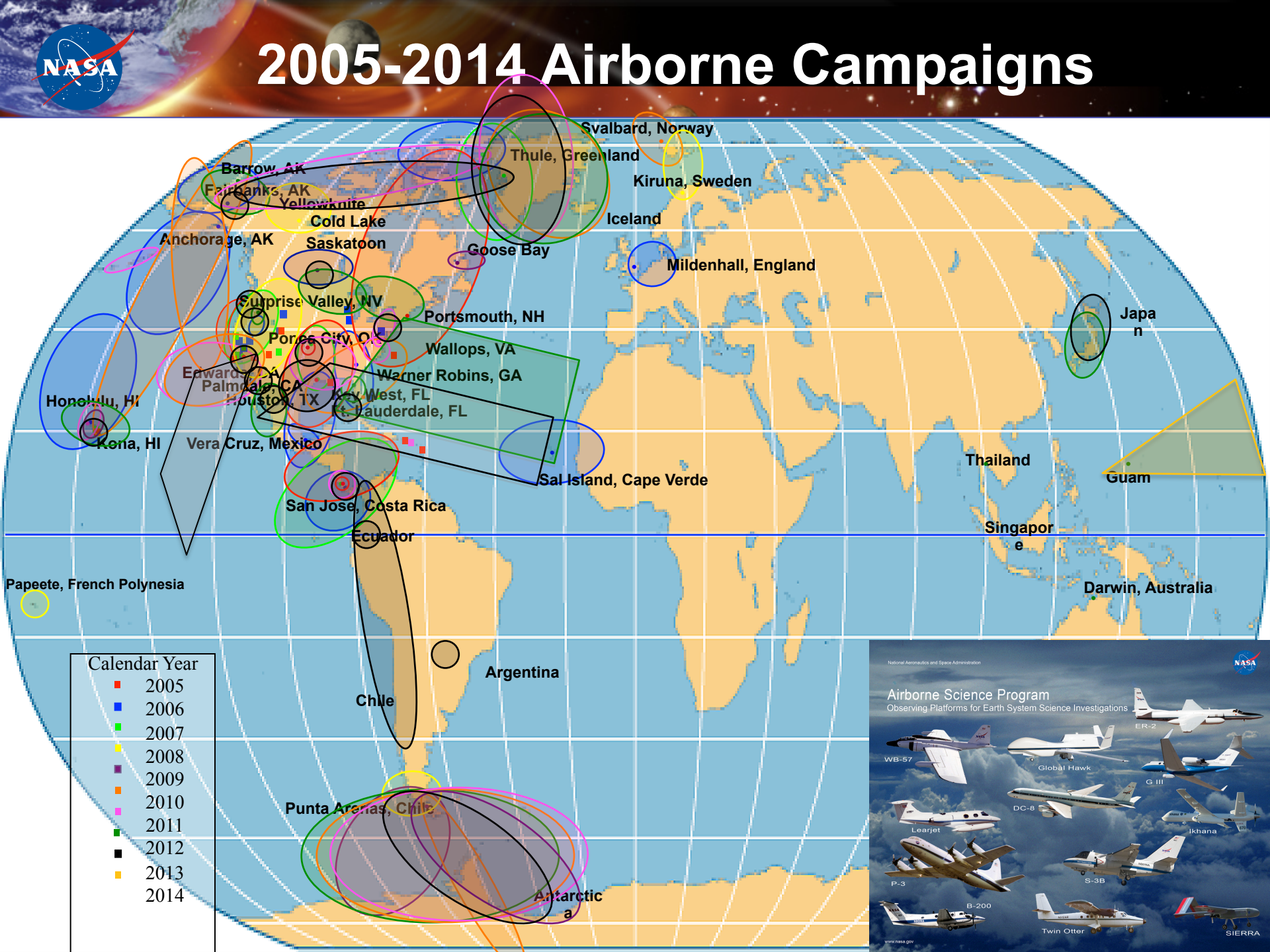


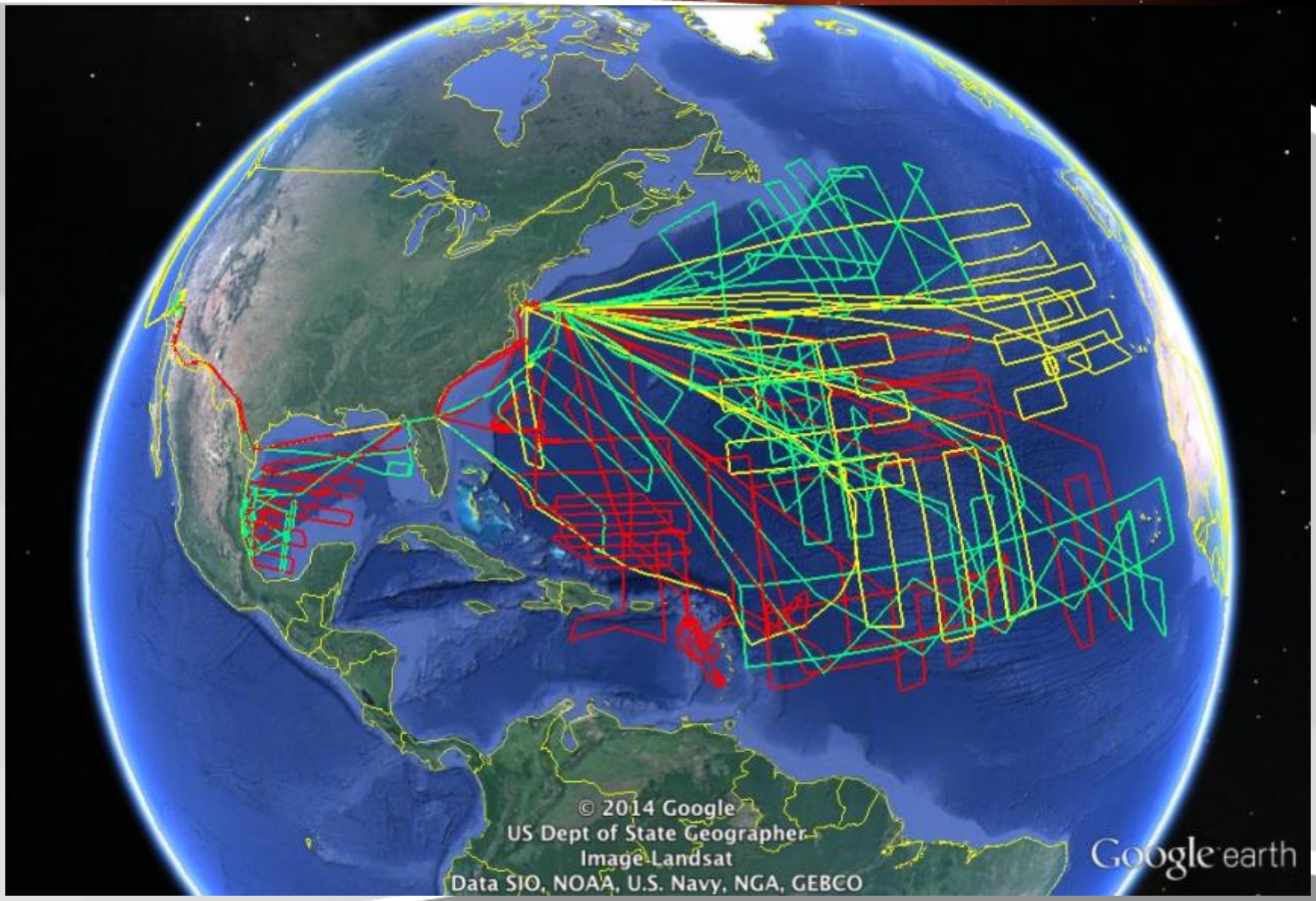
MPLNet

* NASA partners support 53 many instruments

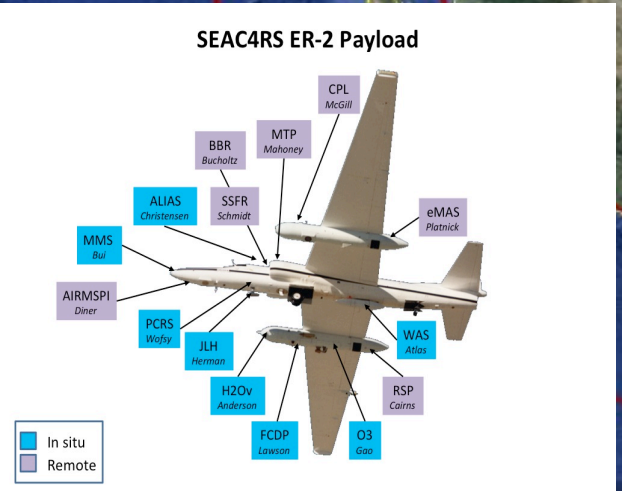
2005-2014 Airborne Campaigns

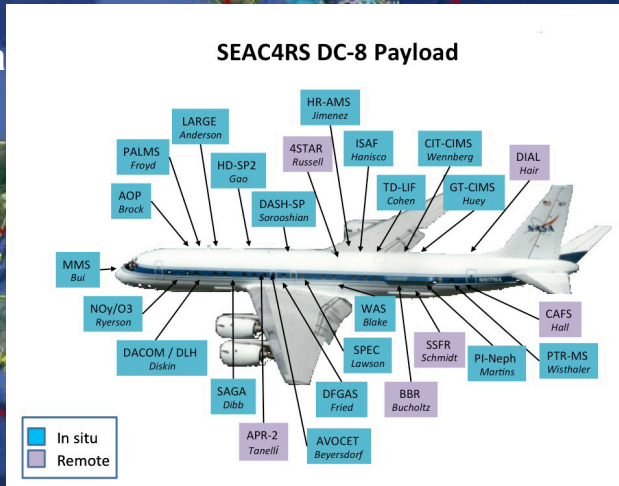


HS3 2012 - 2014



SEAC⁴RS Experimental Approach



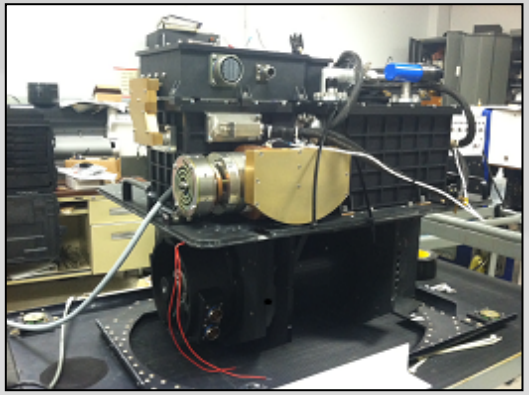


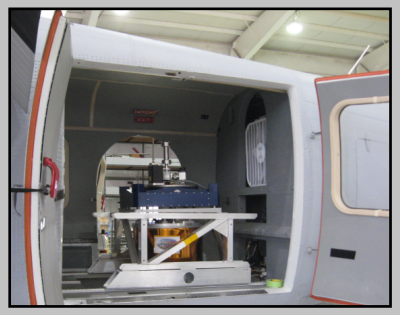
A New Generation of Airborne Sensors …

- Thanks to a variety of recent and current investments (e.g., ARRA, IIP, AITT, …) , NASA is looking at the use and/or development of a new generation of airborne sensors (especially those with “facility-like” operations, as well as PI instruments)!
- Examples include passive optical/infrared sensors, lidars, and radars
- Sensors are designed to work on one or more platforms to facilitate flexible and/or coordinated utilization

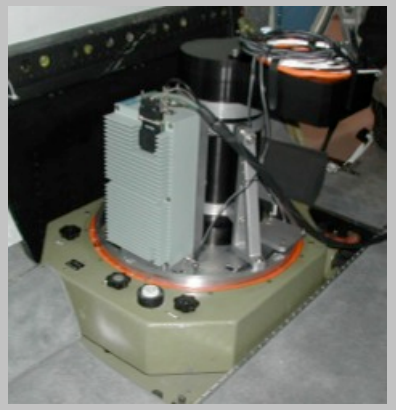
Examples of New Airborne Sensors or those in Continuing Development

- HyTES is a hyperspectral, airborne imaging spectrometer with 256 spectral channels between 7.5 and 12 μm. It currently flies on Twin Otter aircraft but is being adapted to fly on the ER-2

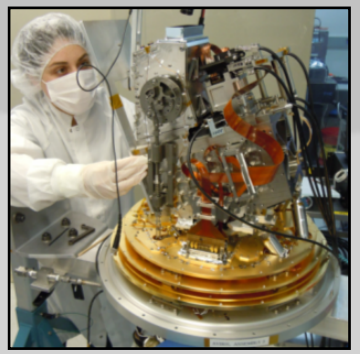




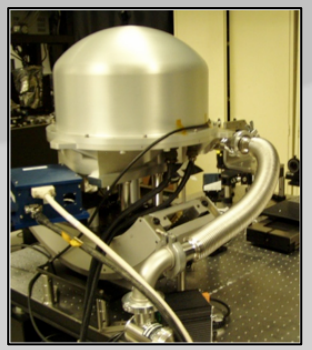
eMAS consists of two bore-sighted imaging spectro-radiometers: eMAS-Scanner: 38 bands (6.7mm – 14.0mm; 3.7mm; 445 – 2400nm) and eMAS-HS Imager: 205 bands 400 – 2450nm DI 10nm; they simulate satellite observations, validate radiances, And prototype future imager requirements



LVIS is a lidar designed to study surface features (canopy height, crevasse depth) that is being "facilitized" for future broad use



AVIRIS-ng extends capaiblities of AVIRIS-c with higher spectral resolution and SNR



PRISM covers the spectral range from 350 to 1050 nm at 2.85 nm resolution, with two longer wavelneth channels

NASA Earth Exchange (https://nex.nasa.gov)

NEX is a virtual collaborative that provides resources (core data sets, software/workflows, and computing) for data- and compute-intensive, NASA-supported Earth science grand challenges.

DIRECT

API

WORKFLOW

API Access (Python, later MATLAB, Java and possibly other languages)

Data Management	Tools and Algorithms	Models	Compute Interface
- Access - Archive - Acquisition - Metadata	- Data Analysis - Data Manipulation (Mostly integrated command-line tools)	- TOPS -BGC -LPJ -WRF ...	- Distributed Computing - Shared Memory (Others possible at later date - Hadoop, GPU, ..)

Direct Access

Workflow Access

Data:
LANDSAT, AVHRR
MODIS(Land, Atmosphere)
ASTER, TRMM, FLUXNET, FIA
NCEP/NCAR Reanalysis, PRISM
DAYMET, CRU-NCEP
North America Regional MERRA Reanalysis
Landcover, DEM, STATSGO

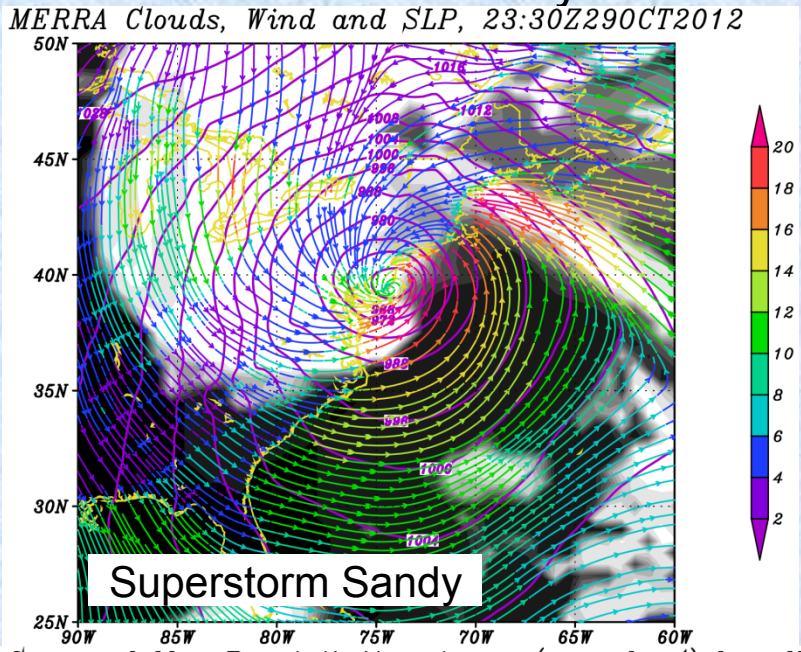
Compute:
SGI ICE cluster
184 racks (11,776 nodes)
129,024 cores
1.79 petaflops, peak
1.24 petaflops LINPACK rating
237 terabytes of memory

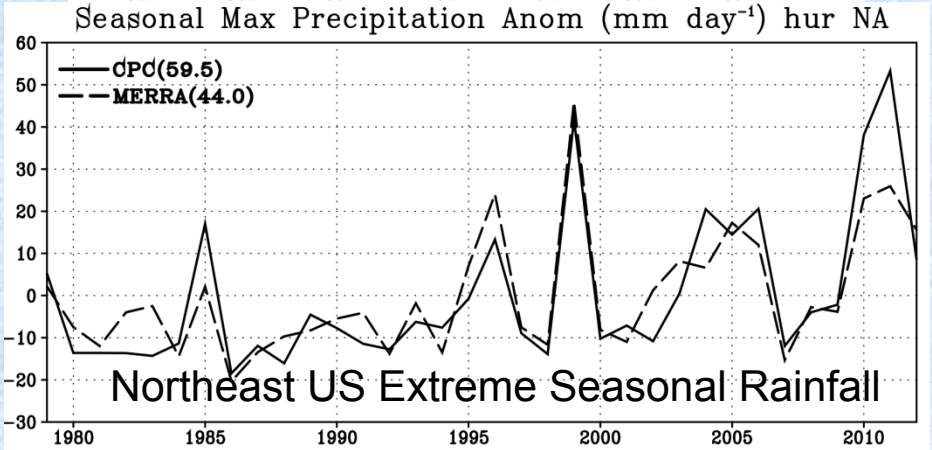
Storage:
Online:
9 petabytes of RAID disk capacity

Archive Capacity:
115 petabytes

Modern Era Retrospective-analysis for Research and Applications

Objectives: characterize, understand, predict using NASA's observations and so acquire deeper scientific understanding of the components of the Earth system and their interactions



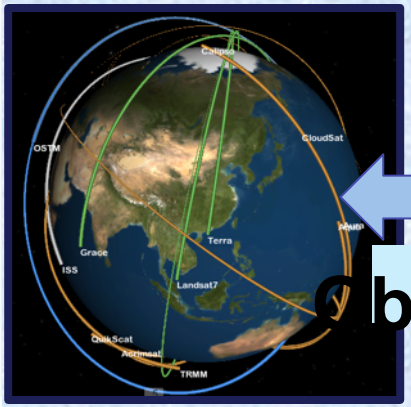


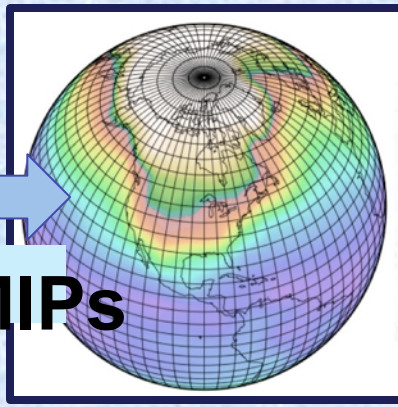
- Development: Utilize diverse NASA observations for the Earth System weather and climate
- Advance Diagnostics
  - MERRA-Land: Bias corrected land surface data
  - Hourly data for over 35 years
  - Complete budgets
  - Surface – Stratosphere
- MERRA2 New Developments
  - Interactive assimilated Aerosols
  - Bias corrected surface Precip
  - Water Budget Mass Constraint
  - Tropical Cyclone Relocator

obs4MIPs
CMIP & ESGF

The Coupled Model Intercomparison Project (CMIP) data is disseminated via the Earth System Grid Federation (ESGF) to climate analysis community for use in IPCC Assessment

obs4MIPs satellite data sets are hosted side by side and in the same file format as the GCM output to facilitate ready use by the analysis community.





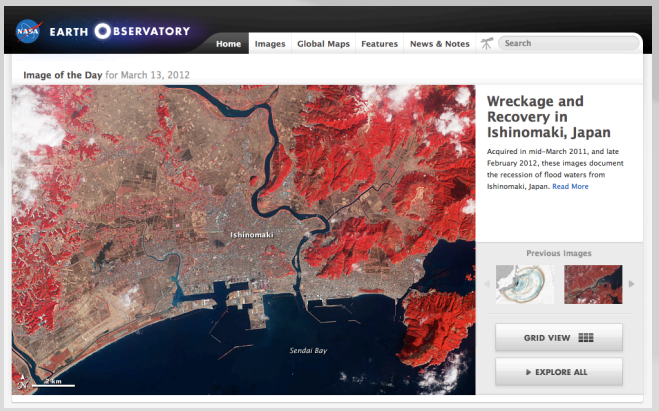
obs4MIPs

Communications Tools for NASA's Global Environmental Data

Eyes on the Earth-3D Website*

Dynamic Planet

NASA Earth Now I-Phone App



Earth Observatory Web Site

Climate.nasa.gov web site

NASA Hyperwall

*Software demonstrated to audience at US Center at COP-18 meeting in Doha, Qatar

Overview of Talk

- Introduction – A Top Down View of the Earth
- How NASA Studies the Earth with Remote Sensing
- The Interagency and International Context
- What We're Learning
- Future Plans
- It's not ALL Satellites
- Some thoughts about the Future …
- Conclusion

Looking ahead (>15 years?): A Personal view

- *A potential long-term vision*: To make NASA-provided environmental data and products central to helping the world's citizens, businesses, and governments sustainably and safely thrive in an ever-changing planet

- Global observing capability routinely and affordably providing timely, trusted, and innovative environmental information on Earth System and its response to naturally-occurring and human-induced change
- Data delivery and modeling systems designed and implemented to provide actionable data to users at earliest possible opportunity to support use in research, forecasting, and decision-making
- Partnerships that leverage the capabilities of governmental, private sector, and non-profit entities to facilitate and assure widest possible use of NASA-provided environmental information

NASA Earth Science:
What Won't Be Different, What Is Enduring

- A focus on scientific rigor in all that we do, especially calibration/validation of observations to support integration into multi-instrument/multi-platform data sets, and process knowledge needed to understand and interpret observations and enhance predictive capability
- Outstanding relationship with the research community, including that at NASA centers, academia, industry, and other government agencies, and a community-influenced research program that contributes to and benefits from our observational capability
- Active participation in interagency and international coordinating mechanisms to assure programmatic integration and maximizing societal benefit of NASA investments
- Significant presence in low Earth orbit, especially over the poles
- Committed stewardship of NASA-produced data, and an open data policy that sets a world standard through "leading by example" for openness and access.
- Continued investment in technology that helps "create our future" through development of both new approaches/capabilities and improvements in existing ones that may reduce cost and/or increase accuracy and/or lifetime
- Our ability to inspire future scientists and inform the citizens of the future

NASA Earth Science:
Key Technical Challenges (already in work)

Temporal Sampling: Emphasis on higher-temporal sampling of key parameters that change within a day, or to capture extreme events

- Higher-altitude orbits and/or use of satellite constellations
- Venture Class (CYGNSS, TEMPO) is providing initial test of this.

Third Dimension: Increased emphasis on vertical profiles (height) for looking at key elements of Earth system, especially atmosphere and oceans.

- CALIPSO has been pathfinder on value and technical capabilities

- *Spectral Information*: Still significant opportunities to harness and exploit parts of the electromagnetic spectrum; advances in technology and computing are making this much more feasible.
  - Airborne demonstrators: UV for oceans, hyperspectral IR for biosphere & land surface

- *Real- and Near-Real time Data Availability*: Applications value of data is enormously enhanced with such availability; science needs to study key events. Advances in tools for rapid downlinking, processing (incl. on-board), and distributing.
  - "LANCE" system to support users and to test and advance approaches

- *Modeling & Visualization*: Increased capabilities to provide scientific results and information at scales useful to decision makers of all types. Interest in observationally-informed modeling are greater, requiring greater investments.
  - NASA capabilities in support of NCA

NASA Earth Science:
Key Programmatic Challenges (already in work)

- *Partnerships.* Increased range and intensity of partnerships (public, private, civil society) to ensure benefits of data reach broadest possible user communities through existing/evolving mechanisms. Implications for workforce skills and capabilities.

- *Data Availability & Utilization.* Increased emphasis on utilization of full set of global data from all providers, but changing mix of data providers and continuing evolution of ideas about commercialization of data. Promotion of open data policies and focus on nurturing partnerships necessary for availability of global data for science and applications.

- *Workforce*. A diverse work force to develop technology, pursue and further advance Earth science, manage diverse partnerships, and utilize/ exploit the data and modeling for environmentally-informed decision-making by governments and businesses.

- *Citizen Science*. A more engaged citizenry in pursuit of Earth science (e.g., citizen scientists) and informed personal decision-making.

NASA Earth Science:
Key Programmatic Challenges – continued

- *Continuity & Innovation.* If NASA is expected to provide continuity for an ever-increasing range of observations, especially to support operational purposes, our ability to innovate becomes limited. Need for self-consistent guidance that allows for innovative and executable program.

- *Social Science.* Recognition at national (e.g., USGCRP) and international(e.g., Belmont Challenge, Future Earth) levels that understanding Earth system evolution needs better understanding of the human dimensions. Need for deliberate strategy for integration of natural and aspects of social, behavioral, and economic sciences – whether that comes from interagency/international partnerships or from within NASA.

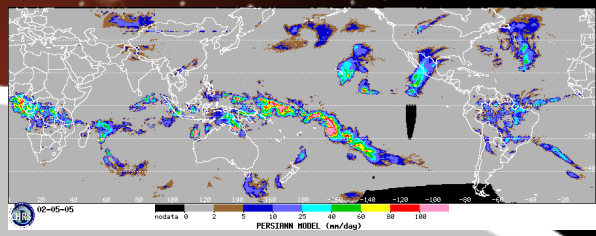
- *Public-Private Relationships.* As private sector becomes more engaged in use (and possibly production) of Earth science knowledge and data, they will become more engaged with community in identifying research priorities. There will be a need to address priority setting to ensure balance among fundamental, use-inspired, and applied research while assuring availability of data for scientific and societal needs.

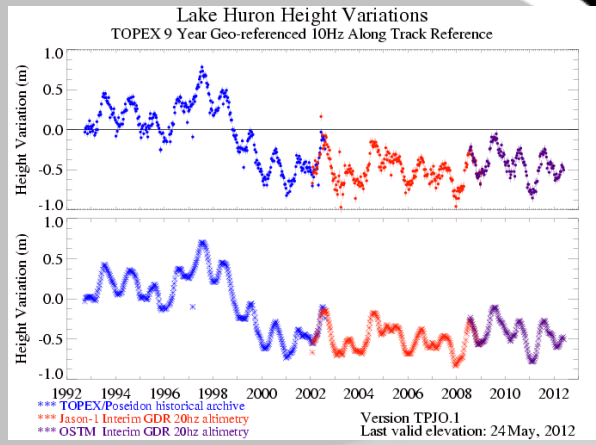
Example: Fresh Water Availability

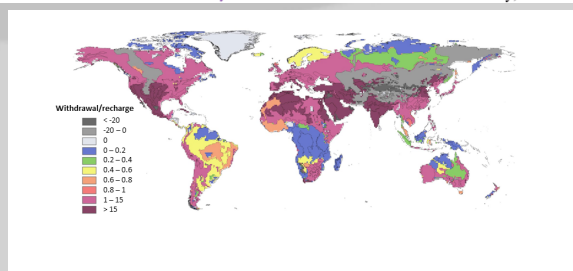
The Problem: Today, nearly one Billion people do not have access to fresh water. Water scarcity undermines agricultural productivity, public health and the GDP of many nations and ultimately undermines the political stability of some. "Water" has become a threat to *our* national security

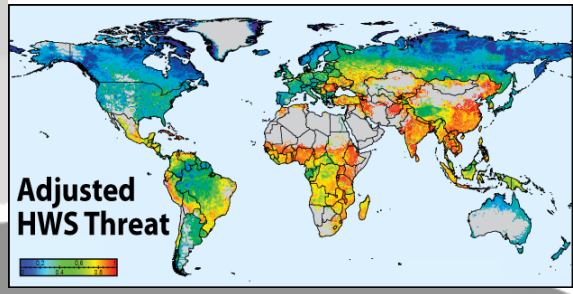
The Challenge: Increasing population, warmer temperatures, changing precipitation patterns and timing of snowmelt will combine to exacerbate existing challenges of fresh water availability as we progress in the 21st century. This will be a particular problem in developing countries and those currently dependent on snowmelt and ice runoff.

The Opportunity: Observations and models pioneered by NASA, together with domestic and international partnerships, will enhance society's ability to manage in the face of water scarcity.









Fresh Water Availability (2)

NASA's satellites will provide:

- High-frequency information on global precipitation
- Frequent observations of extreme rainfall events
- Distribution of snow and its valuable water content
- River stage and runoff, lake and reservoir holdings
- Soil moisture measurements
- Glacier height/mass and surface melt state
- Evaporation for agricultural consumption and/or water holding/moving losses
- Early warning of potentially dangerous water quality situations
- Rapid data delivery mechanisms (space➔ground➔modeler➔user)
- NASA research and models to support well-characterized assimilation of broad range of data into forecast models

The Outcome: Domestic and international forecasters, water managers, water users, and private and non-profit sector stakeholders are confidently using NASA-produced information to better help the world's population to meet its water availability needs.

Potential Progress in Addressing Global Sustainability Issues: Fresh Water Availability

Where we are now	Where we could be …
Good climatology of liquid precipitation in tropics and subtropics with little knowledge of diurnal variation on global scale	Excellent climatology of world-wide liquid and solid precipitation, transmitted routinely and rapidly to a global community of users
Low resolution, low frequency data about ground water distribution for major aquifers	Routine information of ground water and aquifer depletion/recharge at spatial and temporal scales of use by water managers
Demonstrated capability to measure soil moisture with models and observations designed for other purposes	Global high resolution soil moisture, evaporation, and associated crop conditions for routine use by the agricultural industry
Demonstrated capability to measure river stage and lake height with systems designed for other purposes	Global, high frequency measurements of river stage and lake height for major rivers and lakes provided routinely to water managers
Observations of snow extent but little knowledge of water storage (snow water equivalent)	Global measurement of snow extent and water storage (snow water equivalent) provided routinely to water resource managers
Research-based water cycle models that assimilate limited data types	Water cycle models assimilating a full range of NASA data and closely linked to water decision processes

2014 ~ 2030

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Concluding Messages

- The vantage point of space provides a good approach to watch the whole planet evolve and explore the interconnections between physics, chemistry, and biology
- The current and projected suite of space-based environmental measurement capability enables scientific discovery and (for many parameters) monitoring, and is being enhanced by introduction of new technology (!)
- Current observations show significant changes in many aspects of earth system, especially in polar regions, with the potential for even more significant changes in the future
- Impacts of potential climate change for civilization are significant and require strong scientific knowledge base that supports action as well as an interdisciplinarily-oriented workforce
- Investments in space measurements are synergistic with surface-, aircraft-, and balloon-based measurements, along with models

Your Planet is Changing

Earth Right Now

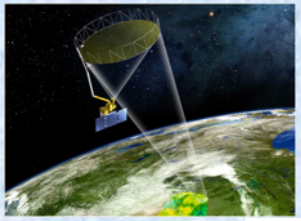
We're on it!

GPM

OCO-2

ISS-RapidScat

CATS



SMAP